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ABSTRACT

This publication is the third of three sequential course manuals for instructors in X-Ray science and engineering developed at Oregon State University. It consists of outlines of thirteen lectures, and six laboratory exercises with problems and three examinations. Also included is a list of references, equipment, and material. The purposes, teaching aids, materials, time recommendations, and reference materials are given for each lecture and laboratory exercise. Some of the lectures and laboratory exercises are X-Ray film, sensitometric properties of X-Ray films, medical radiography, research applications of X-Rays, and X-Ray therapy. (Author/BB)

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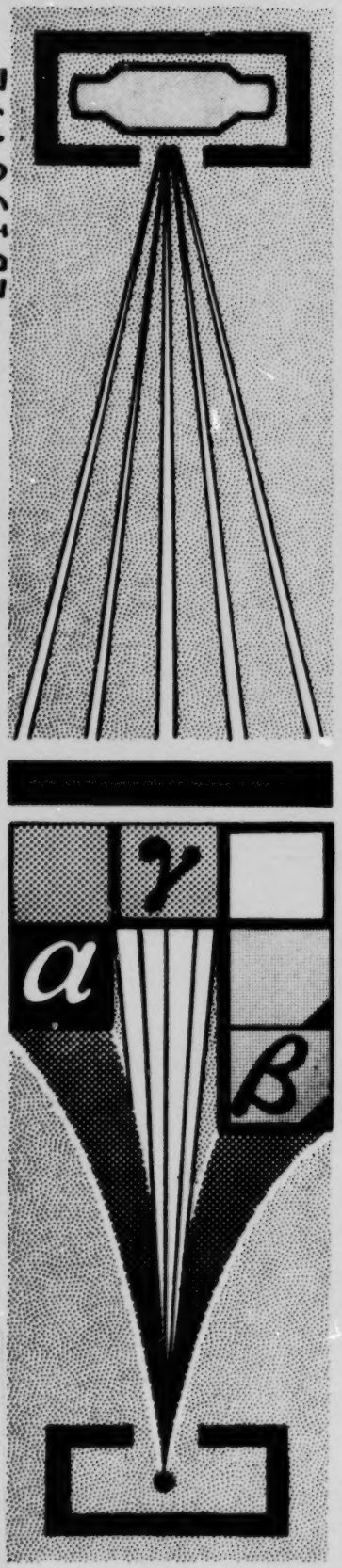

COURSE MANUAL for X-RAY APPLICATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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SE 024 453

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FDA 76-8049 Radiation Protection During Medical X-Ray Examinations - Part 5, Gonad Shielding in Diagnostic Radiology (National Audiovisual Center (GSA), Washington, D.C. 20409, $39.00).

FDA 76-8051 Directory of Personnel Responsible for Radiological Health Programs (superseded by FDA 77-8016).

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FDA 76-8053 The Double-Edged Sword (Flyer).

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FDA 77-8004 Biological Effects of Ionizing Radiation: An Overview (GPO 017-015-00117-2, $0.65*, and $1.00**) (PB 262 453/AS, mf only).

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COURSE MANUAL
for
X-RAY
APPLICATIONS
(GS-463)

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Bureau of Radiological Health

This work was carried out under PHS Contract Number 223-72-6314.

BRH
bureau of radiological health

WHO Collaborating Center for
Training and General Tasks in
Radiation Medicine

(This publication supersedes HEW Publication (FDA) 73-8028, January 1973)

July 1977

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Food and Drug Administration
Bureau of Radiological Health
Rockville, Maryland 20852

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FOREWORD

The Bureau of Radiological Health conducts a national program to limit man's exposure to ionizing and nonionizing radiations. To this end, the Bureau (1) develops criteria and recommends standards for safe limits of radiation exposure, (2) develops methods and techniques for controlling radiation exposure, (3) plans and conducts research to determine health effects of radiation exposure, (4) provides technical assistance to agencies responsible for radiological health control programs, and (5) conducts an electronic product radiation control program to protect the public health and safety.

The Bureau publishes its findings in appropriate scientific journals and technical report and note series prepared by Bureau divisions and offices. Under a memorandum of agreement between the World Health Organization and the Department of Health, Education, and Welfare, three WHO Collaborating Centers have been established within the Bureau of Radiological Health, FDA:

WHO Collaborating Center for Standardization of Protection Against Nonionizing Radiations (Office of the Bureau Director)

WHO Collaborating Center for Training and General Tasks in Radiation Medicine (Division of Training and Medical Applications)

WHO Collaborating Center for Nuclear Medicine (Division of Radioactive Materials and Nuclear Medicine)

As a WHO Collaborating Center, the Bureau makes available its technical reports and notes to participating WHO members.

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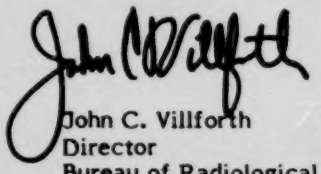

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

Within the Bureau of Radiological Health, the Division of Training and Medical Applications is responsible for programs to reduce unnecessary radiation exposure to the public by improving the practices of those who use radiation in the healing arts. An important aspect of this work is the development and distribution of educational materials, both for students in the health care professions and for the continuing education of individuals who are already in practice.

In 1965, the X-Ray Science and Engineering Laboratory of Oregon State University, under a contract with the Bureau of Radiological Health, initiated a three-course sequence in X-Ray Science. These courses were designed for students who have had no x-ray experience but have had at least 1 year's work in college level physics and mathematics. The manuals developed for use in these courses were made available in 1973 by the Bureau through the Superintendent of Documents, U.S. Government Printing Office. This new set of manuals has been prepared to reflect new technology, new reference material, and the experience gained in teaching. They are also being made available by the Bureau through the U.S. Government Printing Office.

There are three course manuals in this set, one for each course in the sequence. The courses are:

461 Machine Sources of X Ray
462 X-Ray Measurements
463 X-Ray Applications

These manuals are intended for the instructor's use in planning and presenting the courses. Each manual contains lecture outlines and laboratory exercises. An attempt has been made to present the subject matter in as uncomplicated a form as possible. In doing so, some concepts may have been oversimplified but the instructor can increase the degree of sophistication to the limit of student understanding.

The project was directed by the late Dr. E. Dale Trout, Professor of Radiological Physics, and an internationally recognized expert in the fundamentals and use of x radiation. Dr. Trout was assisted by John P. Kelly, Associate Professor, Department of General Science. We welcome comments on your experience with this manual.

James S Benson

James S. Benson, Project Officer
Deputy Director
Bureau of Radiological Health

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INTRODUCTION

In 1965, the X-Ray Science and Engineering Laboratory of Oregon State University, under a contract with the Bureau of Radiological Health, Food and Drug Administration, Department of Health, Education and Welfare, initiated a three-course sequence in X-Ray Science. The Course Manuals developed for use in this course were made available in 1973 by the Bureau of Radiological Health through the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

The Course Manuals as used at Oregon State University are updated each year to reflect new technology, new reference material, and the experience gained in teaching. At the end of the 1974-1975 academic year it was thought advisable to prepare a new set of Manuals as used during that year.

There are three Course Manuals in this set. They are used in a three-course sequence offered in the Department of General Science at Oregon State University.

The courses are:

GS-461 Machine Sources of X Ray - Fall Term
GS-462 X-Ray Measurements - Winter Term
GS-463 X-Ray Applications - Spring Term

The courses must be taken in sequence. Each is a 3-hour credit course and consists of two 1-hour lectures and one 3-hour lab each week. These courses are open to both undergraduate and graduate students. The manuals are intended for the instructor's use in planning and presenting the courses. It is assumed that students will have had no x-ray experience but that they will have at least 1 year's work in college level physics and mathematics.

An attempt has been made to present the subject matter in as uncomplicated form as possible. In so doing some concepts may have been oversimplified, but the instructor can easily increase the degree of sophistication to the limit of student understanding.

An attempt has been made to make each lecture and each laboratory exercise a self-contained entity. This has been done to permit selection of material that could be used to fit the available time, the use of available equipment and the objective of the instructional program.

The equipment has been identified by model and by manufacturer to enable the instructor to substitute equivalent equipment or to alter the course content to make use of available equipment. This method of identification does not constitute a recommendation of a particular piece of equipment by either Oregon State University or the Bureau of Radiological Health, Food and Drug Administration, United States Department of Health, Education and Welfare.

The objective has been to present certain basic material in a manner that will permit great flexibility in the manner in which it is used. We have for 10 years used the manuals for a three-course sequence of classes that have included students from programs in 30 academic disciplines. About 75 percent of the students are premed or predent. Since our courses include things basic to

radiation usage and good practice, students have come from programs in veterinary medicine, physics, geology, electrical engineering, radiation biology, oceanography, fisheries and wildlife, production engineering, nuclear engineering, chemistry, and pharmacy; to name some of them.

Selected sections have been used for a one-term course in Continuing Education and some sections have been presented as 2-day, working, topical seminars.

It is our belief that full appreciation and understanding of the subjects presented require laboratory experience. The lecture material alone could be presented as review material or as indoctrination material to a group where x rays might be of peripheral interest.

One of the more frustrating things encountered in the preparation of a teaching outline such as this is the ever-changing situation so far as references are concerned. New books and technical papers may make any list of references obsolete before such a document appears in print. The instructor must add books and references as they become available. The references cited should always reflect the experience, interests and objectives of the instructor, the institution, and the student.

E. Dale Trout, Project Director
X-Ray Sience and Engineering Laboratory
Oregon State University

April 14, 1976

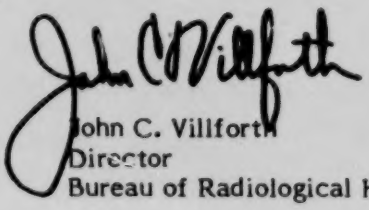
ABSTRACT

Course Manual for X-Ray Applications (GS-463) is an instructor's guide consisting of an outline of lectures and laboratory exercises with problems and examinations. Included is a list of references, equipment, and materials.

The designation GS-463 is the course number at Oregon State University and it is carried throughout the text. The course is offered by the Department of General Science.

IN MEMORIAM

With Dr. Trout's death in February 1977, the Bureau of Radiological Health lost a valued colleague. Dr. Trout contributed his unique expertise to the Bureau's advisory committees, and to the development of both our diagnostic x-ray performance standard and training programs in the area of medical radiation. Many of the Bureau's senior staff members received their original training in radiological health from Dr. Trout at Oregon State University. Over a period of many years, he served us well as a counselor, a teacher, and a friend. We will miss him.



John C. Villforth
Director
Bureau of Radiological Health

August 4, 1977

SECTION I. LECTURES

GS-463. X-RAY APPLICATIONS

LECTURE NO. 1

TITLE: X-Ray Film

PURPOSE: To outline the history of photographic and radiographic film and discuss the composition and manufacture of x-ray film

TIME: 1 hour

VISUAL AIDS: Blackboard

HANDOUTS: None

REFERENCES:

Attix, Roesch and Tochilin
Radiation Dosimetry

Eastman Kodak Company
Medical Radiography and Photography Vol. 46, No. 3, 1970

Mees and James
The Theory of the Photographic Process

1. X-RAY FILM

I. History

A. Early history of photographic film

1. 1802 - silhouettes on glass recorded by contact printing on paper coated with silver chloride. Images were transient.
2. 1816 - film used in camera produced transient negative image
3. 1839 - basis for chemical development of photosensitive materials established
4. 1840 - negative positive photography established
5. 1847 - paper negatives used until 1847. Glass plates coated with albumen emulsion introduced.
6. 1851 - wet collodion glass plates
7. 1871 - dry gelatin glass plates
8. 1879 - mechanically coated gelatin glass plates
9. 1885 - stripping film with paper emulsion support
10. 1889 - cellulose nitrate emulsion support
11. 1890 - science of photographic sensitometry by Hurter and Driffield

B. Radiographic film

1. 1895 - photographic glass plates
2. 1914 - single coated cellulose nitrate films
3. 1918 - duplitized film
4. 1924 - cellulose acetate film base
5. 1933 - tinted film base to enhance contrast
6. 1936 - direct exposure film
7. 1940 - film suitable for both direct and indirect exposure
8. 1958 - fast light sensitive film
9. 1960's - polyester base and films for rapid processing

II. X-RAY FILM (fig. 463-1)

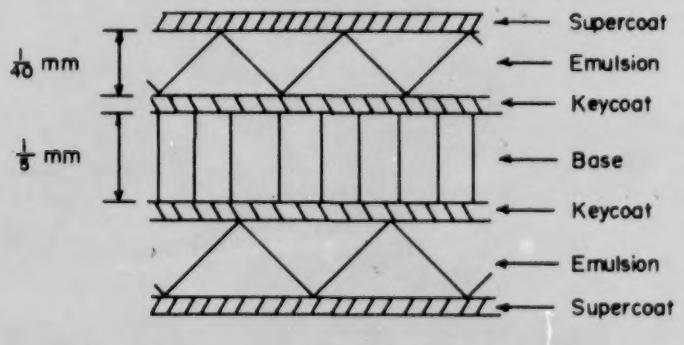


Figure 463-1. Composition of x-ray film.

A. Supercoat (T-coat, anti-stress layer, anti-abrasion layer)

1. Thin layers of clear gelatin
2. Normally 0.1 - 0.5 micron thick
3. Protects underlying emulsion

B. Emulsion

1. Layer of gelatin in which grains of silver bromide are suspended
2. Each grain about 1 micron in diameter (fig. 463-2)

Figure 463-2. Silver bromide grain.

3. One grain has 10^9 - 10^{10} atoms
   Approximately 10^9 grains/cm^3
4. Can be a few microns to several thousand microns thick
5. Speed of film depends on grain size

   a. Speed: exposure required to obtain a certain density
   b. Large grain - fast film
   c. Small grain - slow film

C. Key coat (subbing layer)

1. Gelatin and solvent
2. Serves as bond between emulsion and base

D. Base

1. Transparent plastic

   a. Presently polyester
   b. Formerly cellulose triacetate

2. Supports fragile emulsion layers

III. X-RAY FILM MANUFACTURE

A. Gelatin - transparent organic material

1. Preparation

   a. Use calf's hide
   b. Lime wash to remove fat and hair
   c. Acid wash to remove lime
   d. Gelatin extracted by pressure cooking
   e. Gelatin concentrated

2. Properties
   a. Soluble in hot water
   b. Insoluble in cold water
   c. Insoluble at normal developing temperatures
   d. Swells and absorbs liquid without dissolving
   e. Can be shrunk and hardened into solid state

B. Silver salt (AgBr)

1. Suspended in gelatin. Portion of film that produces the image
2. Preparation

   a. Pure Ag and HNO_3 yield $AgNO_3$
   b. AgBr formed by mixing KBr solution and $AgNO_3$ solution
   c. AgBr crystals are cubic (fig. 463-3)

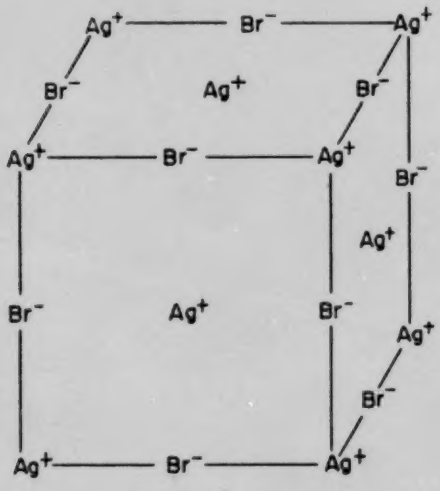


Figure 463-3. Silver bromide crystal.

C. Sensitizing agents

1. Make emulsion react to low-energy photons

   a. Forms sensitive sites
   b. Focal points of reaction

2. Sensitizer

   a. "Mustard oil"
   b. Few drops per ton of emulsion
   c. Mustard oil treated with alkali and reacts with AgBr to form sensitive sites

D. Emulsion

1. AgBr and gelatin mixed to form suspension. Total darkness.
2. Suspension coated on base
3. Grain size controlled by rate and temperature of mixing

a. Rapid mix, low temperature, fine grain
b. Slow mix, higher temperature, larger grains
c. Ripening process

4. Typical emulsion 50 grains deep
5. Typical grains triangular or hexagonal with thickness 1/5 diameter
6. Washing
   Ripened emulsion cooled, shredded, washed
7. Digestion

   a. Emulsion remelted, held at constant temperature for about 1 hour
   b. Sensitizing (sulfur) agents added

E. Film coating

1. Dust free, total darkness
2. Temperature and humidity controlled
3. Coated on both sides
4. Film sheets (40 inches wide, 1,000 feet long)

   a. Cooled and cut to size
   b. Packaged

LECTURE NO. 2

TITLE: Latent Image Formation

PURPOSE: To discuss the nature and mechanism of formation of the photographic latent image

TIME: 1 hour

VISUAL AIDS: Blackboard

HANDOUTS: Eastman Kodak Company, Medical Radiography and Photography Vol. 46, No. 3, 1970

REFERENCES:

Eastman Kodak Company
Medical Radiography and Photography Vol. 46, No. 3, 1970

General Aniline & Film Corporation
Radiography, a Tool of Medical Science

Gevaert
Medical X-Ray Films

Mees and James
The Theory of the Photographic Process

2. LATENT IMAGE FORMATION

I. FORMATION

A. Radiation induces change in an AgBr grain

B. Renders grain susceptible to the action of a developer

C. Evidence that latent image is silver

1. Chemically analyzed and found to be silver
2. Chemical reactions which oxidize silver also destroy latent image

II. GURNEY-MOTT THEORY (1938)

A. Crystal of silver bromide consists of orderly array of silver and bromine in cubical structure (fig. 463-4)

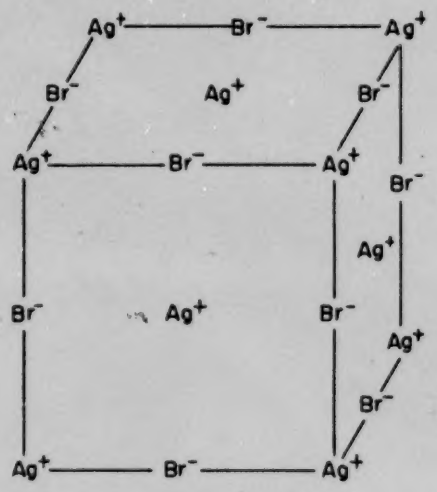


Figure 463-4. Silver bromide crystal.

1. Perfect crystal of no value photographically
2. Sensitizer (sulfur compound) produces region on surface of grain called sensitivity speck
3. This region has the ability to trap electrons

B. Light exposure (x-ray exposure with intensifying screens)

1. Bromine ion absorbs light photon and loses its valence electron

$$Br^- \xrightarrow{h\nu} Br + e^-$$

2. Energy level diagram (fig. 463-5)

Figure 463-5. Energy level diagram.

Most sensitive to green light of 5000 Å

3. Valence electron trapped at sensitivity speck
4. Interstitial silver ion (ion lying within crystal lattice) moves to electron trap site and combines with the electron

$Ag^+ + e^- \rightarrow Ag$

5. Silver atom unstable until process repeated several times building up accumulation of silver atoms at site

   a. Exact number of silver atoms required to make developable latent image not known
   b. Probably between 10 and 100

6. Neutral bromine ions formed leave crystal and move to the surrounding gelatin
7. If only one light photon interacts with crystal only one silver atom is formed

   a. Atom will decay unless more silver atoms are formed
   b. Therefore rate dependence exists

8. Reciprocity law

   a. States that response of film, for example, photographic density, to a given total exposure of a given type of radiation is independent of the rate at which the exposure was administered
   b. Depends only upon intensity (I) of light and time (t) of exposure
   c. Deviation from reciprocity law is termed "reciprocity law failure"
   d. Reciprocity law holds for films exposed directly to x rays but fails for films exposed to light (fig. 463-6)

      (1) Low mA, long time; some Ag atoms will decay before stable image is formed
      (2) High mA, short time; electrons released at high rate

         (a) Migrate to sensitivity speck more rapidly than silver ions
         (b) Electron potential created at speck unless Ag+ added at same rate as e^-
         (c) Only one e^- required to start reaction

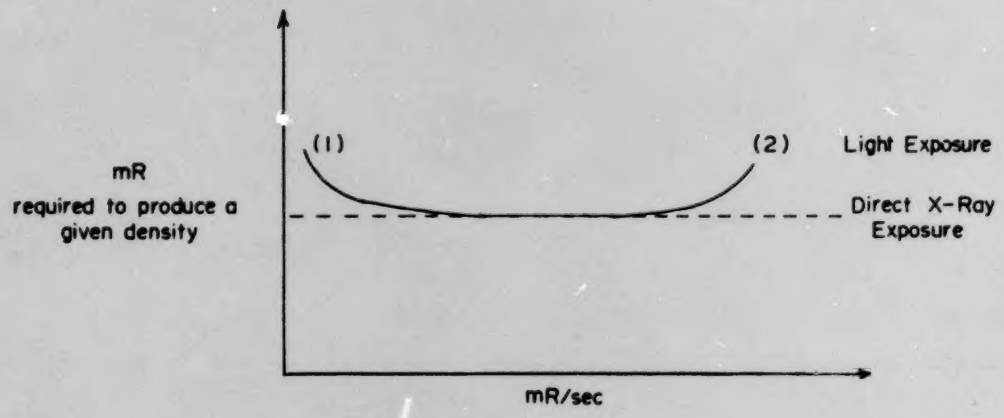


Figure 463-6. Reciprocity law failure.

(d) Results in repelling actions between electrons and some will be lost and not contribute to latent image production
(e) Such extremes in exposure rate are required to produce reciprocity law failure that it is not of significance in normal radiography

(3) Reciprocity law failure may make it appear that the inverse square law is not valid

C. Direct x-ray exposure

1. X-ray photon interacts somewhere within emulsion producing photoelectron
2. High-energy electron passes through one or more grains and produces latent image
3. Secondary electrons produced within grain may number up to 1,000

   a. Migrate to speck
   b. "Single hit" phenomenon

4. Reciprocity law holds.

LECTURE NO. 3

TITLE: X-Ray Film Processing

PURPOSE: To discuss the chemical actions and procedures used in processing exposed x-ray film

TIME: 2 hours

VISUAL AIDS: Blackboard

HANDOUTS: Fuji Photo Film Company, Ltd. Processing and Handling of Medical X-Ray Films, 1972

REFERENCES: Eastman Kodak Company
Principles of the Kodak X-OMAT Processing System

Ilford, Ltd.
X-ray Processing

Mees and James
The Theory of the Photographic Process

3. X-RAY FILM PROCESSING

I. BASIC PROCESS

A. Development of latent image

B. Fixation of latent image

C. Rinsing away of processing chemicals

D. Drying the film

II. THEORY OF DEVELOPMENT

A. Developer converts silver bromide grains with latent image to metallic silver without affecting grains not containing latent image

1. Developing solution provides electrons and reduces AgBr to Ag

AgBr	+	e^-	→	Ag + Br^-
(Containing latent image)		(Provided by developer)		

2. Bromine ion taken up in gelatin and eventually in the developing solution

B. Exterior of AgBr grain has negative barrier because of bromine ions at the surface and absorbed bromine from developer (fig. 463-7)

Figure 463-7. AgBr grain without latent image.

1. Attempt to developer to donate e^- is opposed by this barrier
2. Formation of latent image causes break in barrier (fig.463-8)

a. Electrons from developer can penetrate grain
b. Converts AgBr grain to metallic silver

Figure 463-8. AgBr grain with latent image.

III. DEVELOPING SOLUTION

A. Four basic ingredients

1. Developing agents (electron donors)

a. Reduces Ag^+ to metallic Ag
b. Combination of hydroquinone and elon or phenidone

2. Alkali

a. Activates developing agents
b. Sodium carbonate or sodium borate
c. Softens and opens up gelatin for developer
d. Speed of developer partially dependent on degree of alkalinity

3. Preservative

a. Used to prevent oxidation at surface of solution by contact with air and subsequent staining of the gelatin
b. Sodium sulfite

4. Restrainer (bromine ions)

a. Minimizes development of unexposed grains
b. Number of bromine ions increases as films are developed and developing agent becomes depleted
c. Necessary to replenish solution with fresh chemicals (or extend developing time)

B. Replenishment

1. Purpose is to renew concentration of developing solution to original strength
2. Accomplished by adding concentrated solution to original developer solution
3. Generally recommend not to replenish more than 3 - 4 times

IV. STOP BATH

A. Stops activity of developer
B. 3-1/2 percent acetic acid

V. FIXING SOLUTION

A. After development emulsion contains exposed, developed AgBr grains and undeveloped AgBr grains. Gelatin is spongy and saturated with developing agents, alkali, sodium sulfite, bromine ions and development products.

B. Purpose of fixer

1. Stop development process
2. Dissolve unexposed AgBr grains
3. Harden gelatin

C. Ingredients

1. Clearing agent

a. Ammonium thiosulfate ("hypo")
b. Dissolves and removes undeveloped AgBr from emulsion
c. Clearing time

(1) Adequate fix = 2 times clearing time
(2) Also allow for hardening of gelatin

2. Acidifier

a. Acetic acid
b. Neutralizes any developer that may have been carried over
c. Necessary for correct action of other chemicals

3. Hardener

a. Salts of aluminum
b. Toughens gelatin
c. Shrinks gelatin to prevent swelling by water absorption in final wash

4. Preservative

a. Sodium sulfate
b. Prevents decomposition of fixer because of air oxidation

D. Replenishment

1. To keep fixer solution at peak strength
2. Maintains minimum fixing time
3. Concentrated fixer solution
4. Replenish when clearing time twice that of fresh solutions

VI. WASH AND DRY

VII. MANUAL (HAND) PROCESSING

A. Film handling

1. Use dry hands
2. Hold film by edges
3. Work using safelite or in total darkness
4. Avoid bending or scratching film

B. Time and temperature

1. Light sensitive film, 5 minutes at 20° C (68° F)
2. Direct exposure film (has thicker emulsion), 5 to 8 minutes at 20° C (68° F) following manufacturer's instructions
3. Typical recommended times and temperatures

Time - minutes	Temperature o C	o F
2	29.4	85
2-1/2	26.7	80
3-1/4	23.9	75
3-3/4	22.2	72
4-1/2	21.1	70
5	20.0	68
6-1/4	18.3	65

4. In all cases follow manufacturer's instructions

C. Film processing technique

1. Development

   a. Stir developer and fixer
   b. Determine temperature
   c. Set timer for recommended development time
   d. Immerse film in developer

      (1) Agitate periodically
      (2) Dislodges air bubbles and keeps fresh solution in contact with film

   e. Eberhard effect

2. Rinse

   a. Running water 10 - 20 seconds
   b. Does not stop development process fast
   c. Stop bath - if available

      (1) Mild acid
      (2) 10 seconds

3. Fix

   a. Agitate periodically
   b. Fix twice clearing time
   c. Follow manufacturer's instructions

4. Wash

   a. Removes chemicals
   b. In running water

      (1) 30 minutes in water flowing at 3-4 volume changes per hour
      (2) Direct exposure film requires longer (2 times) wash than light sensitive film

5. Wetting agent - prevents spotting and streaking
   Immerse 2-3 minutes
6. Dry - 10 to 45 minutes in warm circulating air dryer

VIII. AUTOMATIC PROCESSING (KODAK M6A-N X-OMAT)

A. Use same film handling precautions as for manual processing

B. Film processing

1. The processor automatically controls time, temperature, and replenishment
2. The film is automatically transported from the entrance tray through the developer, fixer, wash and dryer to the exit film bin (fig. 463-9)

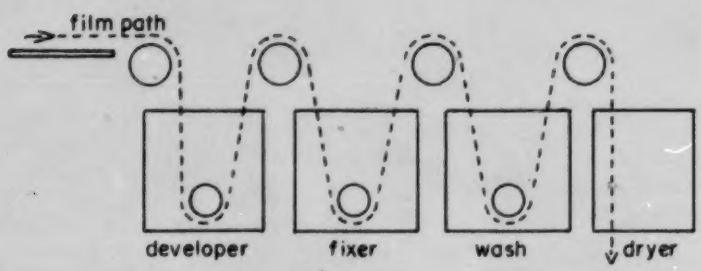


Figure 463-9. X-Omat transport system.

a. Determine that developer temperature is correct 95° F (35° C)
b. Determine that dryer temperature is correct 120° F (48.9° C)
c. Determine that incoming wash water temperature is correct 90° F (32.2° C)
d. Place film on entrance tray and slide film forward until it engages with the first set of rollers

(1) Follow manufacturer's instructions for film orientation and number of films of a given size that can be processed together
(2) Bell in processor will ring when film is in processor and another film can be started into processor

e. Processor automatically transports film and provides proper replenishment

C. Chemistry

1. Special developer and fixer used

a. Manual processing chemicals soften and swell emulsion
b. In roller-transport X-Omat this would cause films to "jam" or stick to rollers
c. X-Omat chemicals control film swelling
d. Roller system forces chemicals into film emulsion

2. Temperature

a. High developer temperature used to rapidly soften emulsion

D. Other systems

1. Modern automatic film processors all work on roller transport principle
2. Special film for automatic processors is available which, with special chemicals, permits complete processing to be accomplished in 90 seconds

LECTURE NO. 4

TITLE: Sensitometric Properties of X-Ray Film

PURPOSE: To discuss the relationship of exposure and processing to x-ray film response

TIME: 2 hours

VISUAL AIDS: Blackboard

HANDOUTS: Eastman Kodak and Gevaert reference

REFERENCES:

Eastman Kodak Company
Sensitometric Properties of X-Ray Films

Gevaert
Sensitometry

Mees and James
The Theory of the Photographic Process

Ter-Pogossian
Physical Aspects of Diagnostic Radiology

4. SENSITOMETRIC PROPERTIES OF X-RAY FILM

I. INTRODUCTION

A. Sensitometry is the study of film response to exposure and/or processing. Factors included in film response are:

1. Contrast
2. Latitude
3. Speed

II. TYPES OF FILMS

A. Screen-type film (medical film, light sensitive film)

1. Used between two intensifying screens, usually $CaWO_4$
2. Sensitive to light emitted by screens when screens excited by x rays
3. Small portion of film density because of x rays interacting in film emulsion

B. Nonscreen-type film (industrial film, direct sensitive film)

1. Density dependent entirely on x-ray interactions in emulsion
2. Less sensitive than screen-type film-slower

III. CHARACTERISTIC CURVE

A. Represents response of film (density) as a function of exposure to light or x rays. Sometimes referred to as sensitometric curve or H. and D. curve after Hurter and Driffield (fig. 463-10).

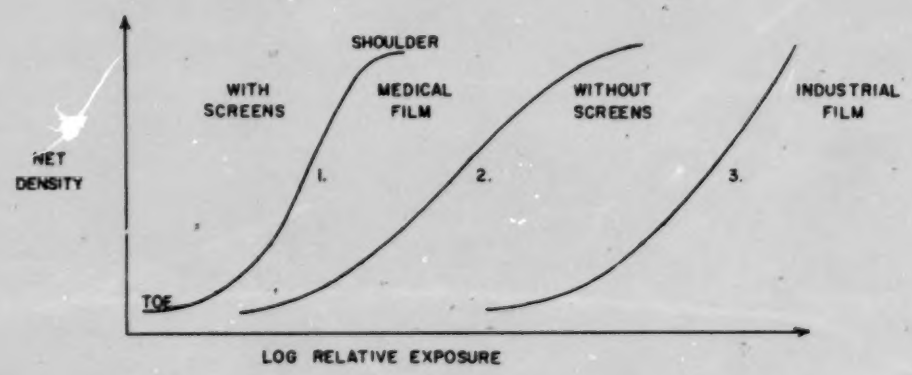


Figure 463-10. Sensitometric curves.

1. Screen film exposed with $CaWO_4$ screens
2. Screen film exposed without screens

a. Broader shoulder
b. Greater latitude

3. Direct exposure film. No shoulder in useful density range.

B. Shape of curve

1. Depends on:

a. Type of film
b. Processing
c. Type of screens

2. Does not depend on x-ray energy (fig. 463-11)

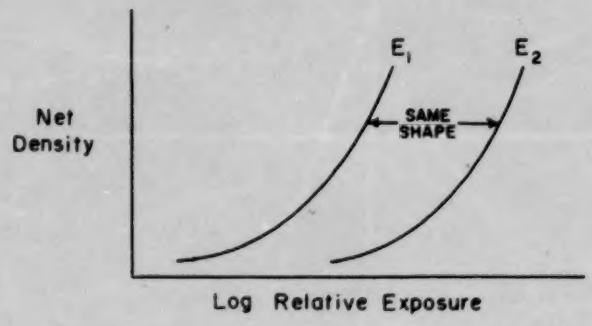


Figure 463-11. Curve shape for two energies.

a. For direct exposure films, displacement of curve depends upon mass absorption coefficient of AgBr
b. For screen films, displacement depends upon mass absorption coefficient of $CaWO_4$
c. As μ/ρ decreases the curve will shift to the right

C. Average gradient - $\overline{G}$

1. Slope of straight line joining the two points of specified density on the characteristic curve (fig. 463-12)

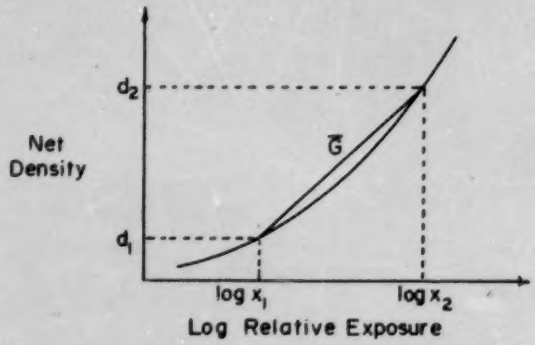


Figure 463-12. Average gradient.

2. $\overline{G} = \frac{\Delta d}{\log_{10} 10^{\Delta X}} = \frac{d_2 - d_1}{\log_{10} 10^{X_2} - \log_{10} 10^{X_1}} = \frac{d_2 - d_1}{\log_{10} \frac{X_2}{X_1}}$

3. Density range (Δd) used in determining average gradient

   a. Medical film, $\Delta d = 0.5 - 2.0$
   b. Industrial film, $\Delta d = 0.5 - 2.5$

4. Average gradient is indicator for film contrast

5. Calculation of average gradient, medical (light sensitive) film

   a. Assume an exposure of 1.1 mR produced a net density of 0.5 and that an exposure of 3.2 mR produced a net density of 2.0

   b. $\overline{G} = \frac{2.0 - 0.5}{\log \frac{3.2}{1.1}} = \frac{1.5}{\log 2.91} = \frac{1.5}{0.464} = 3.23$

6. Gradient

   a. Slope of straight line drawn tangent to the characteristic curve at a point on the curve
   b. Represents contrast properties of film at a point

7. Gamma

   a. Slope of straight line (tangent of angle, θ) portion of characteristic curve
   b. Represents contrast properties of film for straight-line portion of curve (fig. 463-13)

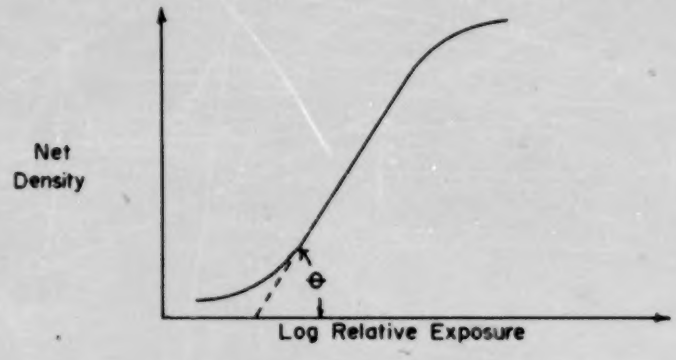


Figure 463-13. Gamma.

IV. FILM SPEED (SENSITIVITY)

A. Reciprocal of exposure required to produce a given density

B. Relative speed (fig. 463-14)

1. Specified film or film-screen combination taken as standard and others compared to it

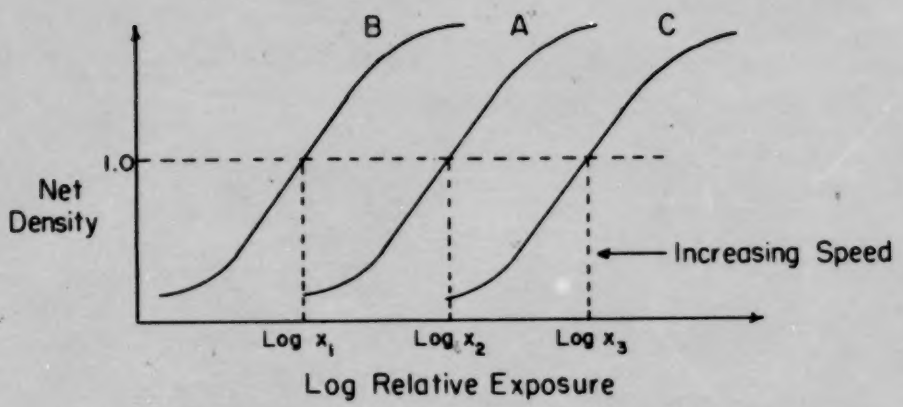


Figure 463-14. Relative speed.

a. Medium speed film or film-screen combination usually taken as standard
b. Standard assigned a relative speed of 100
c. If A is standard and $X_1 = 5$, $X_2 = 10$, $X_3 = 20$ then:

(1) Relative speed of film A = 100
(2) Relative speed of film B = 200
(3) Relative speed of film C = 50

C. Density used in determining speed

1. Can be at any selected density
2. For medical film normally net density 1.0
3. For industrial film normally net density 1.5

D. Factors influencing film speed

1. Film type
2. Processing
3. Screen type
4. X-ray energy

E. Relative exposure

1. More useful in determining exposure required than relative speed
2. Ratio of exposure required to produce given density
3. Standard assigned relative exposure of 1.0
4. In example used for relative speed, the relative exposure would be:

a. Relative exposure of film A = 1.0
b. Relative exposure of film B = 0.5
c. Relative exposure of film C = 2.0

V. RADIOGRAPHIC CONTRAST

A. The contrast between points on a radiograph is equal to the difference in densities (d_1 and d_2 at these points

$$C = d_2 - d_1$$

B. The minimum contract visually detected is about 0.02

C. Subject contrast

1. Results from differences in absorption of radiation by part under examination (fig. 463-15)

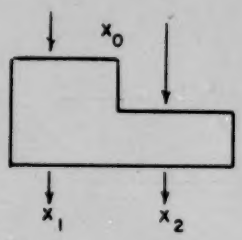


Figure 463-15. Subject contrast.

2. The greater the ratio of X_2/X_1 the greater the contrast
3. The ratio of X_2/X_1 depends upon:

a. Nature of subject

(1) Greater the thickness difference the greater will be X_2/X_1 and contrast will increase

(2) Greater the difference in mass absorption coefficients the greater X_2/X_1 will be and contrast will increase

b. X-ray energy

(1) The greater the x-ray beam energy the smaller will be X_2/X_1 and contrast will decrease

c. Scatter

(1) Scattered radiation tends to reduce X_2/X_1 and therefore reduce contrast

(2) $$\frac{X_2 + X_s}{X_1 + X_s} < \frac{X_2}{X_1}$$

(3) Scatter can be reduced by using a small field size, a grid, an air gap, or reduced x-ray beam energy

(4) Example of effect of scatter on subject contrast

(a) Assume $X_2 = 4$ mR, $X_1 = 2$ mR and $X_s = 1$ mR

(b) With no scatter $X_2/X_1 = 4/2 = 2$

(c) With scatter $(X_2 + X_s)/(X_1 + X_s) = (4 + 1)/(2 + 1)$ $= 5/3 = 1.7$

D. Film contrast (fig. 463-16)

1. Characteristic of film and developing process. Dependent upon slope of characteristic curve.
2. For given object and beam energy the subject contrast is constant. If exposure is increased from X_0 to X'_0

$$\log \frac{X_2}{X_1} = \log \frac{X'_2}{X'_1}$$

3. Increasing exposure moves one to different location on characteristic curve. If slope is different, Δd will change causing change in contrast.

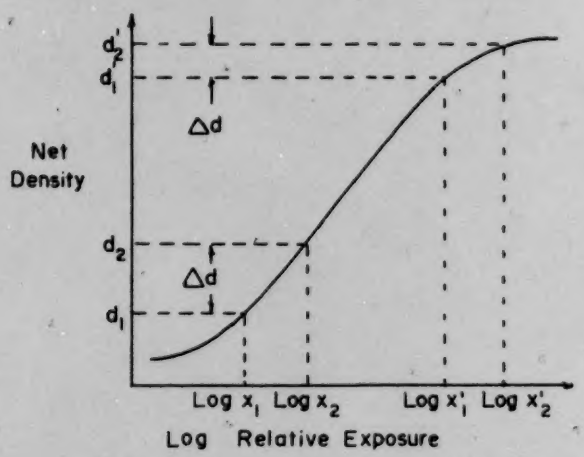


Figure 463-16. Film contrast.

4. Film contrast depends upon:

   a. Film type
   b. Processing
   c. Screen type
   d. Density level

5. Film contrast does not depend upon beam energy

VI. LATITUDE (fig. 463-17)

A. Latitude is the range of exposures over specified density range that is considered useful

B. Latitude is the reciprocal of contrast. Increasing film latitude decreases contrast

C. Film A has greater contrast than film B. Use high contrast film when radiographing uniform areas

D. Film B has greater latitude than film A. Use low contrast film when radiographing objects with high degree of nonuniformity

E. Advantage of wide latitude - exposure requirements not as precise

F. Disadvantages of wide latitude - loss in amplification of subject contrast

G. Usable density range

1. Medical film - to onset of shoulder
2. Industrial film - usually limited by brightness of available illuminator

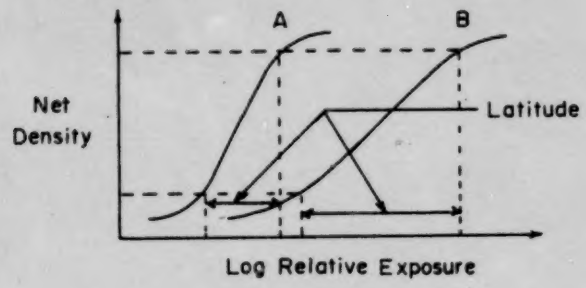


Figure 463-17. Latitude.

GS-463. PROBLEM SET NO. 1

Sensitometry. Refer to the booklet "Sensitometric Properties of X-Ray Film" by the Eastman Kodak Company in answering the questions.

A. The data shown below were obtained when three different x-ray films were exposed using a "sensitometer"

Film A		Film B		Film C	
Exposure-mR	Density	Exposure-mR	Density	Exposure-mR	Density
3	0.28	15	0.20	30	0.28
4	0.36	20	0.26	40	0.35
5	0.46	25	0.35	50	0.43
5.5	0.55	30	0.46	60	0.53
6	0.70	35	0.58	80	0.72
6.5	0.95	40	0.71	100	0.91
7	1.26	45	0.85	150	1.31
8	1.92	50	1.00	200	1.65
9	2.55	60	1.33	300	2.20
9.5	2.85	70	1.63	400	2.64
10	3.00	85	2.07	500	2.91
12	3.24	100	2.45	600	3.08
15	3.37	125	2.95	750	3.23
20	3.45	150	3.36	1000	3.31
Fog	0.20	Fog	0.10	Fog	0.20

1. Determine and plot net density as a function of log exposure.

2. Assuming a useful net density range of 0.5-2.0, which film has the highest contrast? Explain.

3. Assume film B has a relative speed of 100 at density 1.00. What are the relative speeds of films A and C at net density 1.00?

4. Assume film B has a relative exposure of 1.0 at density 1.50. What are the relative exposures of films A and C at net density 1.50?

5. What is the average gradient for each film for a net density range of 0.5-2.0?

6. What is the gradient for each film at density 1.25?

7. Which film has the greatest latitude and which film has the least latitude? Explain.

8. Which of the films would you expect to be "screen" exposure films and which would you expect to be "direct" exposure films? Explain.

B. Define the following terms:

1. Radiographic contrast
2. Subject contrast
3. Film contrast
4. Gradient
5. Average gradient
6. Gamma
7. Relative speed
8. Reciprocity law

GS-463. PROBLEM SET NO. 1
ANSWERS

Part A. 1. Net density versus exposure

Film A		Film B		Film C	
Exposure-mR	Net Density	Exposure-mR	Net Density	Exposure-mR	Net Density
3	0.08	15	0.10	30	0.08
4	0.16	20	0.16	40	0.15
5	0.26	25	0.25	50	0.23
5.5	0.35	30	0.36	60	0.33
6	0.50	35	0.48	80	0.52
6.5	0.75	40	0.61	100	0.71
7	1.06	45	0.75	150	1.11
8	1.72	50	0.90	200	1.45
9	2.35	60	1.23	300	2.00
9.5	2.65	70	1.53	400	2.44
10	2.80	85	1.97	500	2.71
12	3.04	100	2.35	600	2.88
15	3.17	125	2.85	750	3.03
20	3.25	150	3.26	1000	3.11

2. Film A has the highest contrast since it has the highest average gradient (see 5 following). Along the body of the sensitometric curve, a given percentage change in exposure will produce a greater change in density than for film B or C.

3. Relative speed = $\frac{(X_B)\quad(100)}{X}$

Film A R.S. = $\frac{(52)\quad(100)}{6.9}$ = 753

Film B R.S. = $\frac{(52)\quad(100)}{52}$ = 100

Film C R.S. = $\frac{(52)\quad(100)}{133}$ = 39

4. Relative exposure = $(X)(1)/X_B$

   Film A R.X. = (7.7) (1)/69 = 0.11

   Film B R.X. = (69) (1)/69 = 1.0

   Film C R.X. = (205) (1)/69 = 2.98

5. $\overline{G} = \Delta\ d/\log\ X_2/X_1 = 2.0\text{-}0.5/\log\ X_2/X_1 = 1.5/\log\ X_2/X_1$

   Film A $\overline{G}$ = 1.5/log 87/35 = 1.5/0.147 = 10.2

   Film B $\overline{G}$ = 1.5/log 87/35 = 1.5/0.396 = 3.79

   Film C $\overline{G}$ = 1.5/log 300/76 = 1.5/0.598 = 2.51

6. Gradient = slope of curve at density 1.25

   $= \Delta d/\Delta \log X$

   Film A $\overline{G}$ = 1.5/log 8.8/6.2 = 1.5/0.154 = 9.75

   Film B $\overline{G}$ = 1.5/log 91/41 = 1.5/0.347 = 4.32

   Film C $\overline{G}$ = 1.5/log 320/88 = 1.5/0.562 = 2.67

7. Film C has the greatest latitude and film A has the least latitude. Film C will cover a much wider range of exposures for a given density range than will film A and B, i.e., film B has the greatest latitude.

8. Film A is a light sensitive film exposed using screens. It has a relatively abrupt toe and shoulder and the highest speed. Film B has no shoulder evident and is, therefore, a direct exposure film.

   Film C has a broader toe and shoulder so it is a light sensitive film exposed without screens.

Part B. 1. Radiographic contrast - the difference in density between two areas on a radiograph.

2. Subject contrast - the ratio of x-ray intensities transmitted by two selected portions of a subject.

3. Film contrast - slope (steepness) of the characteristic curve of the film.

4. Gradient - the slope of straight line drawn tangent to the characteristic curve at some point on the curve.

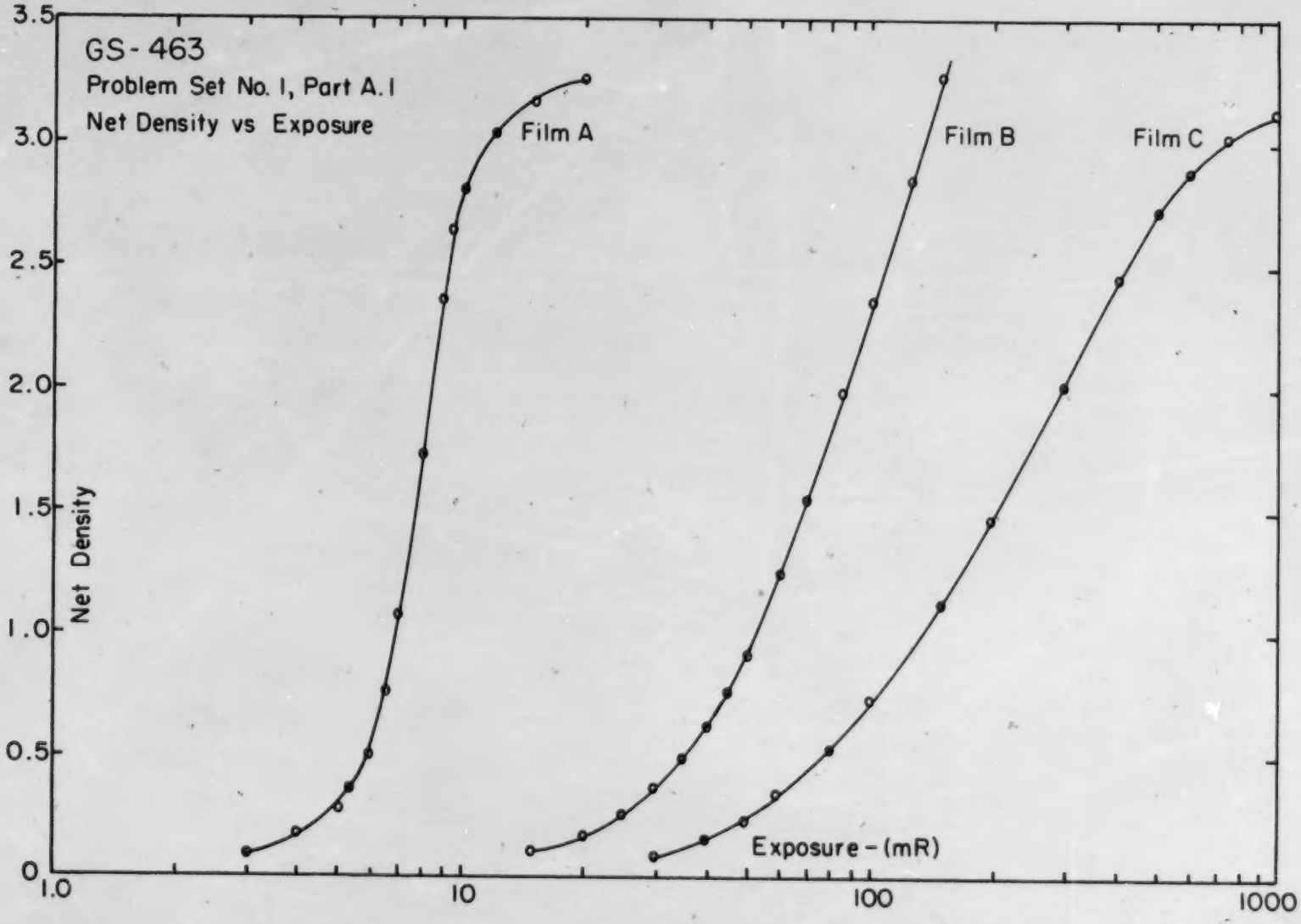
5. Average gradient - the slope of a straight line joining two points of specified densities on the characteristic curve.

6. Gamma - the slope of the straight line portion of the characteristic curve.

7. Relative speed - the speed of one film in relation to another arbitrarily assigned a speed of 100. Relative speed is equal to the exposure required to produce a specified density using the arbitrarily assigned standard film, times 100, divided by the ex-

posure required for the other film to produce the same density, i.e., relative speed = X standard times 100/X unknown.

8. Reciprocity law - the film response (density) is dependent only on the product of intensity and time and is independent of the absolute values of either quantity.


GS-463
Problem Set No. 1, Part A.1
Net Density vs Exposure
Film A
Film B
Film C
Net Density
Exposure - (mR)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
1.0
10
100
1000

LECTURE NO. 5

TITLE: X-Ray Intensifying Screens

PURPOSE: To discuss the construction, characteristics and applications of x-ray screens

TIME: 2 hours

VISUAL AIDS: Blackboard
Cassette with intensifying screens

HANDOUTS: DuPont and Radelin references

REFERENCES:

Curie
Luminescence in Crystals

E. I. DuPont de Nemours & Company
The Care and Use of Cronex Xtra Life Intensifying Screens

Privgsheim and Vogel
Luminescence of Liquids and Solids

Radelin Division of U. S. Radium Corporation
Application, Construction, Characteristics and Care of X-Ray Screens

Ter-Pogossian
Physical Aspects of Diagnostic Radiology

5. X-RAY INTENSIFYING SCREENS

I. INTRODUCTION

A. Radiographic process is very inefficient

1. Efficiency of x-ray production < 1 percent
2. Photons reaching object < 1 percent
3. Photons transmitted through subject < 1 percent
4. Photons absorbed by film < 1 percent

B. Intensifying screens

1. Improve efficiency of radiographic process reducing object exposure
2. Reduce motion by permitting shorter exposure time

C. Used extensively in medical radiography
Exceptions are:

1. Extremities

a. Easily immobilized
b. Low attenuation
c. Fine detail often required

2. Some special procedures such as mammography

II. SCREEN CONSTRUCTION

A. Intensifying screens are mounted in a device called a cassette (fig. 463-18)

1. Screens mounted to top and bottom of cassette
2. Film placed between screens

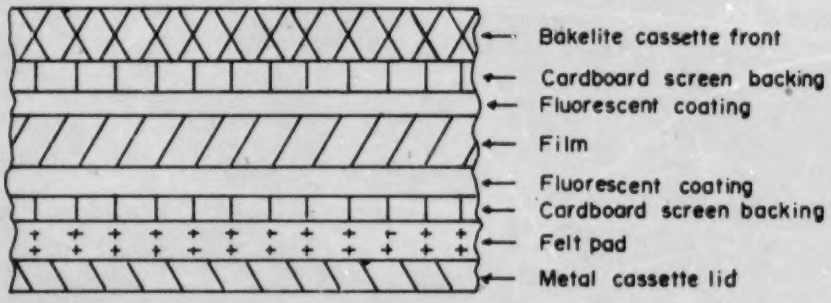


Figure 463-18. Cross section of cassette with intensifying screens.

B. Requirements

1. Emission in desired color band
2. Good x-ray response
3. Stable
4. Uniform quality
5. No afterglow

C. Structure (fig. 463-19)

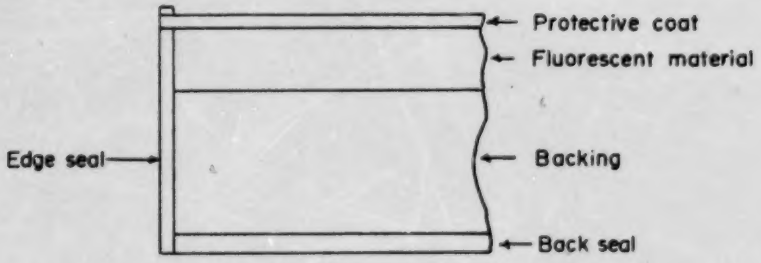


Figure 463-19. Cross section of typical intensifying screen.

III. SCREEN CHARACTERISTICS

A. Phosphors used have ability of absorbing energy from x-ray beam and emitting energy as visible light

B. Phosphor

1. Normally calcium tungstate ($CaWO_4$)
2. Emits light in blue-violet region matching maximum film sensitivity (fig. 463-20)

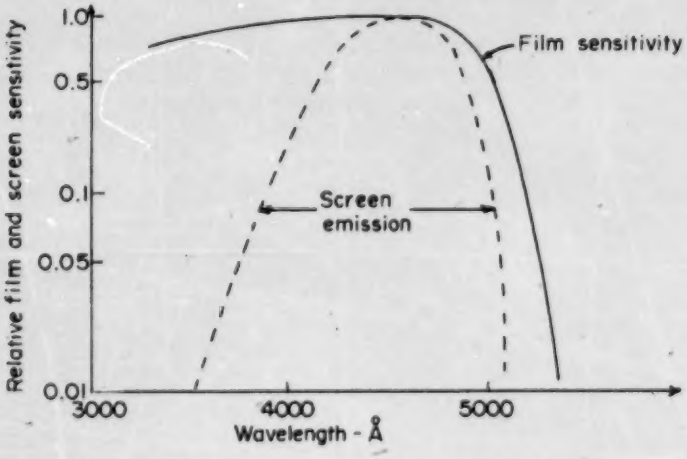


Figure 463-20. Relative sensitivity of films and screens.

C. $CaWO_4$ first used by Edison in 1896

1. From January to March 1896 he investigated over 8,000 materials
2. Found 1,800 that would fluoresce but $CaWO_4$ was best
3. Even tried this as light source

D. Recent phosphors

1. $BaSrSO_4$

   a. Emits light in ultraviolet region requiring film with maximum sensitivity in this region
   b. Used in cassette with curved front and back - closes with rolling action

2. "Rare earths" (gadolinium or lanthanum oxysulfides, and so forth)

   a. Light emitted in green region
   b. Requires green sensitive film for optimum use
   c. Requires different "safe light" for darkroom

IV. SPEED OF INTENSIFYING SCREENS

A. Speed depends upon:

1. Thickness of phosphor layer--the thicker the layer the more energy will be absorbed from the x-ray beam

   a. Speed ∝ thickness (fig. 463-21)

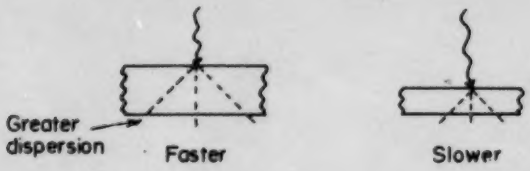


Figure 463-21. Speed versus thickness of intensifying screen.

   b. Greater the thickness the greater the light dispersion, therefore decreased resolution

2. Particle size

   a. Speed ∝ $CaWO_4$ particle size
   b. The larger the size the greater the light dispersion, therefore decreased resolution

B. Factors related to screen speed

1. Intensification factor (I.F.)

   a. Ratio of exposure without screens to exposure with screens to achieve same density

b. I.F. is function of kVp because of changing μ/ρ for AgBr and $CaWO_4$ (fig. 463-22)

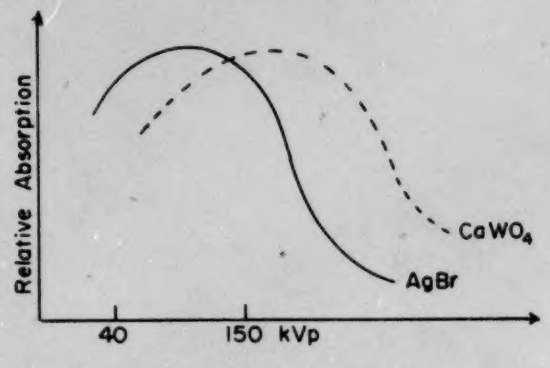


Figure 463-22. Relative absorption of films and screens versus energy.

c. For ballpark number medium speed screens in diagnostic kVp range have I.F. of 30-50

2. Relative exposure factor (REF)

a. Medium speed assigned REF = 1
b. REF for another screen y

$$(REF)_y = (REF)_{med} \left[\frac{X_y}{X_{med}}\right]$$

(1) Same density for each exposure
(2) Same film type

c. If $(REF)_y = 0.5$ then screen y is faster
d. REF depends on beam energy and film type

C. Resolving power of screens

1. Ability to record structural detail
2. Expressed as number of line pairs/mm clearly recorded and can be seen on film
3. If screen can resolve 10 line pairs/mm, each visibly distinct line would be 0.5 mm wide

D. Classification of screens

1. Medium-speed

a. Provide best balance between speed and detail
b. Typical names: Par, standard, universal, mid-speed, and so forth
c. REF = 1.0
d. Resolving power 6 line pairs/mm

2. High-speed

   a. Typical names: Hi-speed, fact, and so forth
   b. "Super high-speed" screens (ultra high-speed) available
   c. Standard high-speed REF = 0.5 and resolving power 5 line pairs/mm
   d. "Super high-speed" REF ≅ 0.35 and resolving power 4 line pairs/mm

3. Slow-speed

   a. Provide increased detail often needed for bone radiography
   b. Typical names: Detail, fine grain, high definition, and so forth
   c. REF = 4
   d. Resolving power 7 line pairs/mm

V. FACTORS AFFECTING SCREEN PERFORMANCE

A. Film-screen contact

1. Warping of cassette front
2. Wrinkled screens
3. Foreign bodies (dust, lint, and so forth)
4. Cracked cassette
5. Worn felt
6. Trapped air
7. Contact can be checked by radiographing 1/4 inch - 1/8 inch brass or copper mesh

B. Temperature

1. Luminescence decreases with increasing temperature

   a. At 43^{o} C (110^{o} F) increase exposure 20 percent
   b. At -10^{o} C (14^{o} F) decrease exposure 30 percent

C. Static marks and artifacts

1. Caused by:

   a. Sliding or shuffling dry films over flat surface
   b. Piling cassettes

LECTURE NO. 6

TITLE: Radiographic Definition

PURPOSE: To discuss the factors which affect radiographic definition

TIME: 1 hour

VISUAL AIDS: None

HANDOUTS: Eastman Kodak reference

REFERENCES:

Bloom, Hollenbach and Morgan
Medical Radiographic Technic

Eastman Kodak Company
The Fundamentals of Radiography

Gevaert
Sensitometry

Johns and Cunningham
The Physics of Radiology

Mees and James
The Theory of the Photographic Process

6. RADIOGRAPHIC DEFINITION

I. SHARPNESS (RADIOGRAPHIC DEFINITION)

A. The more rapid the density change between adjacent areas on a radiograph, the greater will be the radiographic definition or sharpness (fig. 463-23).

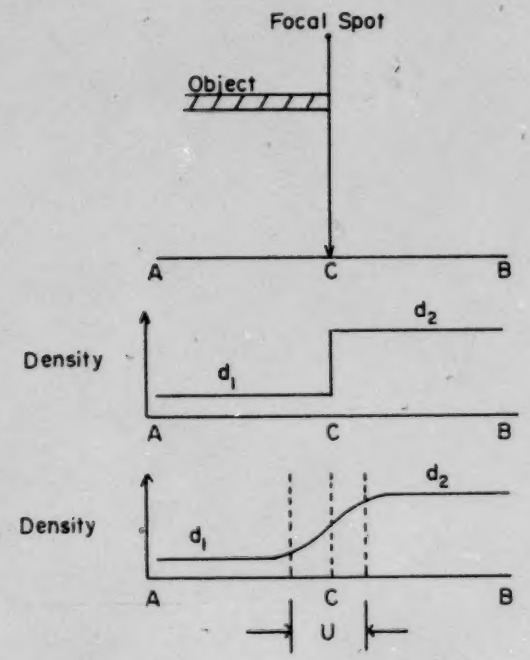


Figure 463-23. Illustration of "sharpness."

B. Radiographic definition is influenced by:

1. Geometric factors
2. Graininess and mottle of the recording media

II. GEOMETRIC FACTORS

A. Focal spot size (fig. 463-24)

1. The smaller the focal spot, the sharper the image
2. A finite focal spot will produce penumbra. Penumbra reduces definition by reducing density gradient.

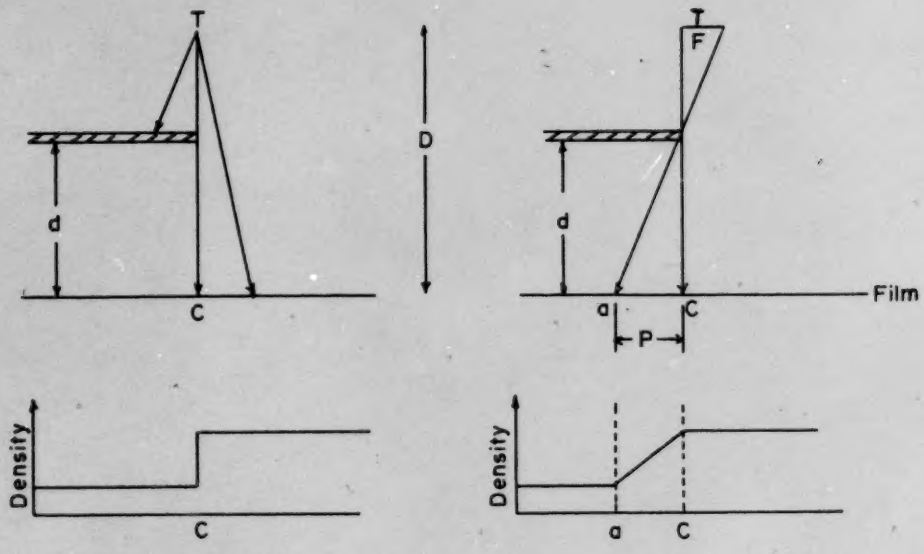


Figure 463-24. Effect of focal spot size on radiographic definition.

3. Penumbra width (P) is given by:

$$P = F\left[\frac{d}{D - d}\right]$$

B. Source-film distance (D)

The greater the SFD, the less the penumbra

C. Object-film distance (d)

1. To minimize penumbra and increase sharpness

   a. Use small focal spot
   b. Use long source-film distance
   c. Use short object-film distance

D. Film-screen contact

1. Light emitted from intensifying screens is divergent
2. Poor film-screen contact will blur image because of greater light diffusion

E. Motion of object or tube or film relative to other two during exposure will blur image

III. GRAININESS AND MOTTLE

A. Radiographic mottle refers to a mottled appearance of radiographs made at very low x-ray exposures as in fast film-screen combinations, for example.

1. Screen mottle

   a. Structure mottle results from structure irregularities of the screen.
   b. Quantum mottle results from statistical fluctuations in the spatial distribution of photons in x-ray image.

      (1) As analogy, consider a long sidewalk on a rainy day. The sidewalk corresponds to the film-screen combination and the raindrops as the x-ray photons.

         (a) Consider a downpour (slow film-screen combination) where an average of 10^4 drops land on each sidewalk square. This is a random process, so each square would not receive precisely 10^4 drops. Some more, some less. The difference between the actual and average can be estimated statistically (Poisson Distribution). If a large number of blocks are involved, the actual number of raindrops on 68 percent of the blocks will differ from the average by no more than σ, the standard deviation.

$$\sigma = \sqrt{\bar{N}}$$

$$\bar{N} = 10^4 \text{ raindrops/square}$$

$$\sigma = 10^2 = 100$$

$$N = 10{,}000 \pm 100 \text{ raindrops/square}$$

$$\% \text{ variation} = \frac{\sigma}{\bar{N}} \times 100 = 1\%$$

Only the remaining 32 percent of the squares will differ by more than this number. Thus, the difference in "wetness" from one square to another will be small and, likely, unnoticeable.

         (b) Consider the same sidewalk in a light rain with the average number of drops per square = 100.

$$\bar{N} = 100$$

$$\sigma = 10$$

$$N = 100 \pm 10 \text{ raindrops/square}$$

$$\% \text{ variation} = 10\%$$

Thus, the difference in "wetness" from one square to another will be much more noticeable in a light shower (10 percent) than in a downpour (1 percent).

   c. Consider the raindrops as x-ray photons

      (1) With a slow film-screen combination, the absorption of 10,000 photons may be necessary to produce a certain density.

(2) With a fast film-screen combination, 100 photons may be required for the same density.
(3) This will lead to a mottled effect.

B. Film graininess results from clumping of developed grains and is independent of the screen.

C. In conventional radiography, structure mottle and film graininess are considerably finer than quantum mottle and are overshadowed by the latter.

D. Greater speed produces more mottle.

E. It is possible to have less apparent mottle with a fast screen, slow film combination than with a slow screen, fast film combination, since greater fast screen thickness tends to diffuse light and reduce the apparent mottle.

LECTURE NO. 7

TITLE: X-Ray Grids

PURPOSE: To discuss the design, construction, and use of x-ray grids

TIME: 1 hour

VISUAL AIDS: Blackboard
Cross sections of grids
Radiographs made using no grid, 8:1, 12:1 and 16:1 grids

HANDOUTS: Liebel-Flarsheim reference

REFERENCES: Hondium Boldingh
Quality and Choice of Potter-Bucky Grids

ICRU Report 10f

Johns and Cunningham
The Physics of Radiology

Liebel-Flarsheim Company
Characteristics and Applications of X-Ray Grids

7. X-RAY GRIDS

I. SCATTERED X RAYS

A. When an x-ray beam passes through a patient, the beam is transmitted, absorbed and scattered.

1. The useful radiographic image is produced by the unattenuated primary beam
2. Scattered radiation will mask the primary beam and reduce contrast
3. Reduced contrast results in decreased visibility of resolution

B. Intensity of scatter depends upon:

1. Density and atomic number of object
2. Volume exposed
3. Photon energy

C. Quantity of scatter reaching the film can be reduced by:

1. Limiting beam to area of interest (reduce volume exposed)
2. Decreasing kilovoltage with appropriate increase in exposure time
3. Using a grid between patient and film to absorb scattered radiation
4. Using an air gap between the patient and the film

II. GRID DESIGN

A. Dr. Gustav Bucky (1913) built the first grid

B. Construction (fig. 463-25)

1. Alternate strips of lead and low density material (pressed paper, balsa wood, plastic, aluminum, magnesium)
2. Thin lead strips in grid (only a few shown in figure 463-25) remove oblique scattered radiation. Primary beam is parallel to the slots (spacers) and transmitted.

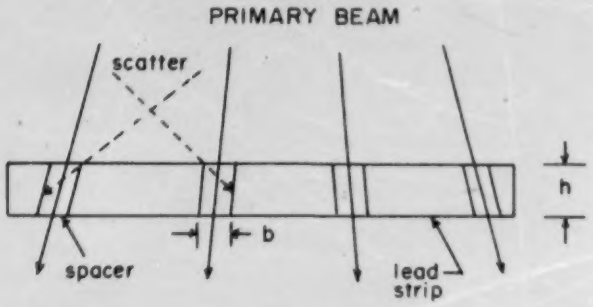


Figure 463-25. X-Ray grid construction.

C. Grid ratio (h/b)

1. Ratio of height to width of spacers between lead strips
2. Grid ratio range 4:1 to 16:1
3. For constant lead strip thickness, the greater the grid ratio the more effective the grid is in removing scatter

D. Grid fineness

1. The number of grid lines (lead strips) per centimeter or per inch
2. Common range 20-60 lines per centimeter (50-150 lines per inch)
3. The more fine, the less visible will be the lines on the radiograph but more primary absorption
4. If lead strips are too thin:

   a. Lose support
   b. No longer effective in stopping scatter

E. Grid types

1. Parallel grid (fig. 463-26)

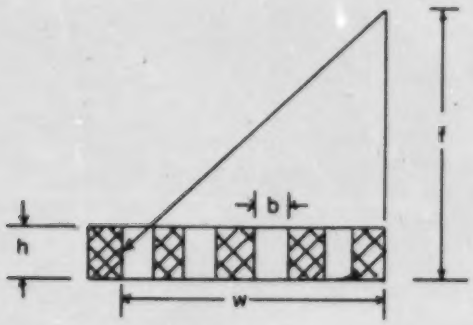


Figure 463-26. Parallel grid.

   a. Cut-off beam will occur as you move away from field center

$$\frac{w}{f} = \frac{b}{h} \quad , \quad w = f \times \frac{b}{h} = \frac{f}{\text{grid ratio}}$$

   b. This will cause gradual reduction in film density on both sides of central beam as cut-off point is reached

2. Focused grid (fig. 463-27)

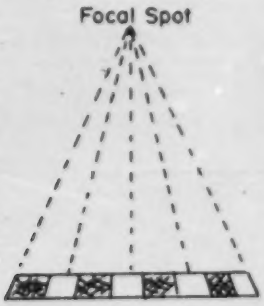


Figure 463-27. Focused grid.

a. Sections of grid about 2.5 cm (1 in.) wide are made
b. Each section positioned at angle pointing toward x-ray tube focal spot
c. No cut-off provided focal spot is at focus of grid
d. Most grids permit some latitude in use but as grid ratio increases, latitude decreases

3. Cross grid (fig. 463-28)

a. Two linear grids placed on top of each other and at right angles
b. An 8:1 crossed grid gives a 16:1 grid ratio
c. Cannot be used with tilting table technics

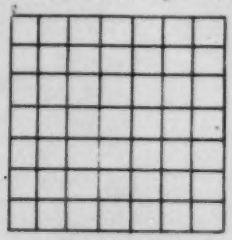


Figure 463-28.
Crossed grid.

F. Moving grids

1. When a stationary grid is used each lead stip shows up as a fine line on the radiograph
2. Movement of the grid during exposure blurs the image of the grid lines
3. Moving grid technic was developed by Dr. Hollis Potter in 1920 (Called Potter-Bucky Diaphragm)
4. Potter devised single stroke system

a. Superseded 1946 by reciprocating Bucky having a fast and slow stroke for use for short exposures
b. Followed 1960 by vibrating continuous motion Bucky

5. Employed in most conventional medical radiographic tables

G. The focused linear grid is best for general purpose radiography

H. As grid ratio increases, three factors become increasingly important:

1. Distance
2. Leveling
3. Centering

I. Current use

1. Vibrating grids in radiographic tables
2. Stationary focused grids in grid-front cassettes
3. Stationary fine-line unfocused grids for high voltage chest radiography and special procedures.

LECTURE NO. 8

TITLE: Medical Radiography

PURPOSE: To discuss the applications of x rays in medical diagnosis

TIME: 1 hour

VISUAL AIDS: Blackboard
Selected radiographs

HANDOUTS: How to Prepare an X-Ray Technic Chart--General Electric
A Guide to Radiological Anatomy--General Electric

REFERENCES:

Bloom, Hollenbach and Morgan
Medical Radiographic Technic

Clark, K. C.
Positioning in Radiography

Greenfield and Cooper
Manual on Radiographic Positioning

8. MEDICAL RADIOGRAPHY

I. FACTORS AFFECTING RADIOGRAPHIC DETAIL

A. Radiographic contrast

1. Subject contrast
2. Film contrast

B. Radiographic definition

1. Geometric factors
2. Mottle

II. MEDICAL RADIOGRAPHIC TECHNIQUE

A. Factors to consider

1. Film type

   a. Relative speed
   b. Contrast and latitude

2. Screen type

   a. Nonscreen (cardboard holders)
   b. Slow
   c. Medium
   d. Fast

3. Grids

   a. No grid
   b. Grid mAs and kVp conversions

4. Collimation

   a. Field size
   b. kVp or mAs change
   c. Gonad shielding

5. Distance

$$\frac{(mAs)_1}{(mAs)_2} = \left[\frac{D_1}{D_2}\right]^2$$

6. Contrast -- kVp, mAs relation

B. Variable kilovoltage technic

1. Keep mAs constant
2. Keep distance constant
3. Vary kVp with part thickness

III. SPECIAL RADIOGRAPHIC PROCEDURES

A. Stereoradiography (fig. 463-29)

1. Three-dimensional radiography
2. Two radiographs are made, one at the position of each eye
3. For a viewing distance of 64 cm (25 in.), the correct tube shift is 1/10 the SFD

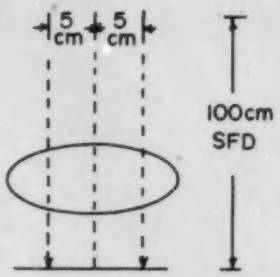


Figure 463-29. Shift for stereoradiography.

B. Photofluorography

1. The image from the fluoroscopic screen is photographed
2. Used in mass chest radiography

C. Cinefluorography -- movies of the dynamic system through the image intensifier

D. Tomography -- body section radiography. Movement of x-ray tube and film provides radiograph of selected plane through body.

E. Rapid Serial Radiography -- consecutive exposure of multiple films to chart the progress of a radiopaque substance

F. Foreign body localization (fig. 463-30)

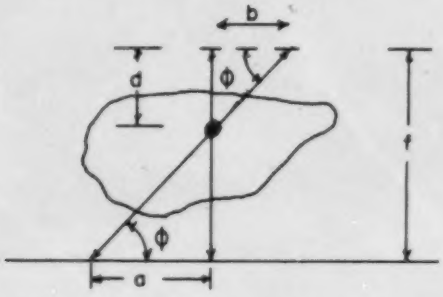


Figure 463-30. Foreign body localization.

$$\tan \phi = \frac{f - d}{a} \quad \text{or} \quad d = \frac{bf}{a + b}$$

G. Contrast studies, angiography, arteriography, cardiac catheterization

NOTE: This lecture is preceded by one or two lectures given by a local radiological technologist who is either head of a technologist teaching program or the chief technologist in an x-ray department. The material covered includes the role of the technologist and his relation to the radiological team and extensive examples of the types of radiological examinations performed in a hospital department of radiology. A 4-hour visit to a local hospital x-ray department, for all interested students, is also arranged.

LECTURE NO. 9

TITLE: Dental Radiography

PURPOSE: To discuss the uses of x rays in dentistry

TIME: 1 hour

VISUAL AIDS: Blackboard
Selected dental radiographs

HANDOUTS: None

REFERENCES: Eastman Kodak Company
X-Rays in Dentistry

Clark, K. C.
Positioning in Radiography

Wuehrmann and Manson-Hing
Dental Radiology

9. DENTAL RADIOGRAPHY

I. INTRODUCTION

A. Use of x rays in dentistry generally accepted as effective means of supplementing physical examination

B. Two general types of radiographic (radiodontic) examinations

1. Intra-oral
2. Extra-oral

II. INTRA-ORAL EXAMINATION

A. Periapical (at or around apex of root of tooth)

1. Entire tooth and surrounding alveolar tissue
2. Film packets

a. 1 or 2 films/packet
b. Standard size 3.2 x 4.4 cm (1-1/4 x 1-3/4 in.)

3. Regions of examinations

a. Maxillary

(1) Central incisor (cutting teeth)
(2) Lateral incisor (L & R)
(3) Cuspid (L & R) (spike teeth)
(4) Bicuspid (L & R) (two-spike teeth)
(5) Molar (L & R) (grinding teeth)

b. Mandibular

(1) Incisor
(2) Cuspid (L & R)
(3) Bicuspid (L & R)
(4) Molar (L & R)

4. Film packets for basic adult examination

a. 9 maxillary
b. 7 mandibular

B. Interproximal (bite-wing)

1. Detect cavities involving approximal tooth surfaces or defects of coronal and cervical regions and interproximal crests
2. Film packets

a. 1 film/packet
b. Sizes, from 2.2 x 3.5 cm (7/8 x 1-3/8 in.) to 2.7 x 5.4 cm (1-1/16 x 2-1/8 in.) depending on location

3. Regions of examinations

a. Maxillary and mandibular

(1) Central incisor
(2) Lateral incisor and cuspid (L & R)
(3) Bicuspid and molar (L & R)

4. Film packets for basic adult examination

a. Average vault 1 - 5 films
b. Narrow vault 1 - 7 films

C. Occlusal (contacting surfaces of teeth)

1. Large areas of maxillae or mandible
2. Film packets

a. 1 or 2 films/packet
b. Size 5.7 x 7.6 cm (2-1/4 x 3 in.)

3. Regions of examinations

a. Maxillary

(1) Incisor
(2) Cuspid-molar (L & R)

b. Mandibular

(1) Incisor
(2) Cuspid-molar (L & R)
(3) Entire mandibular denture

4. Film packets for basic adult examination

a. 3 maxillary
b. 4 mandibular

D. Exposure factors

1. 65 - 100 kVp
2. 20.3 - 40.6 cm (8-16 in.) SSD
3. 10 - 15 mA
4. 1/60 - 1-1/2 seconds

III. EXTRA-ORAL EXAMINATION

A. Not routine

1. Provide supplementary information
2. Of value in specific cases

B. Types of examinations

1. Mandible and Maxillae

a. Lateral
b. Posteroanterior

2. Temporomandibular articulation
3. Facial profile

C. Film

1. Size

a. 12.7 x 17.8 cm (5 x 7 in.)
b. 16.5 x 21.6 cm (6-1/2 x 8-1/2 in.)
c. 20.3 x 25.4 cm (8 x 10 in.)

2. Type

a. No-screen
b. Medium speed
c. High speed

D. Exposure factors

1. 65 - 100 kVp
2. 40.6 - 183 cm (16 - 72 in.) SSD
3. 10 - 15 mA
4. 1/20 - 1-1/4 seconds

IV. SPECIAL EQUIPMENT

A. Panoramic

1. Extra-oral technic
2. Tube and film move around head
3. Provides complete dental radiograph on single film
4. Similar to medical tomography

B. Intra-oral

1. Grounded tube anode placed in oral cavity
2. Film wrapped around face.

LECTURE NO. 10

TITLE: Industrial Radiography

PURPOSE: To discuss the use of x rays in industrial nondestructive testing

TIME: 2 hours

VISUAL AIDS:
- Blackboard
- Selected radiographs
- Selected industrial penetrameters
- Slide projector and slides of typical industrial installations and radiographs

HANDOUTS: None

REFERENCES:
- Eastman Kodak Company
  Radiography in Modern Industry
- Halmshaw
  Physics of Industrial Radiology

10. INDUSTRIAL RADIOGRAPHY

I. INTRODUCTION

A. Nondestructive testing method

B. Examination of single pieces to continuous production line work

II. THE INDUSTRIAL RADIOGRAPH

A. Distinction between radiographic quality and sensitivity

1. Radiographic quality

a. Depends on total radiograph
b. If inspection is of irregular thickness castings, then consideration of thickness latitude, as well as sensitivity, is needed
c. If inspection is to determine orientation of components, sensitivity may be minor factor in radiographic quality

2. Radiographic sensitivity

a. Depends on limits to dimensions of defects which can be revealed

B. Sensitivity

1. Thickness sensitivity

S_T = thickness of thinnest visible plate placed on top of part divided by thickness of part x 100 percent

2. Detail (hole) sensitivity

S_N = thickness (diameter) of smallest hole in plate divided by thickness of object x 100 percent

III. PENETRAMETERS

A. Used to measure sensitivity

1. Purpose

a. Specify radiographic technic by quoting a value of penetrameter sensitivity for the radiograph to be acceptable
b. Evaluate sensitivity in different parts of radiograph
c. Evaluate unexpected or unpredicted variations which affect radiographic quality

2. Desirable characteristics

   a. Sensitive in readings to changes in radiographic technic
   b. Easy and simple to read
   c. Easy to use
   d. Small, so as not to obscure parts but not so small as to be mistaken for object defect
   e. Economical
   f. Identification of size

3. Designs of penetrameters have been based on wires, holes, balls, grooves, slits, and so forth.

B. Step penetrameters

1. 1.25 cm (1/2 in.) square steps
2. Holes centered in steps

C. Plaque penetrameters

1. Plate of uniform thickness
2. 3 holes of different diameters in plate
3. Lead identification numbers

D. Penetrameter codes

1. Essentially the same type of penetrameter is mandatory for all
2. ASME (boiler code), ASTM, military standards
3. Equivalent sensitivity assigned on assumption that a 2T (T = plaque thickness) hole in a 2 percent plaque is described as 2 percent penetrameter sensitivity
4. Penetrameters of thickness T with 3 holes, 1T, 2T, 4T
5. Levels of sensitivity are listed as 2- 2T meaning a 2T hole is perceptible in a 2 percent plaque (2 percent equivalent sensitivity)

IV. APPLICATIONS

A. Foundry practices -- development of casting technics and evaluation of castings

B. Weldment inspection -- flat plates, tubes, pressure vessels

C. Food inspection and processing

V. INDUSTRIAL X-RAY SOURCES

A. Thin metal sections

1. 50 kVp
2. No screens

B. Light alloys (5 inch aluminum to 1 inch steel)

1. 150 kVp
2. No screens or lead foil screens

C. Steel

1. 3.75 cm (1-1/2 in.), 150 kVp, no screens
2. 5 cm (2 in.), 250 kVp, lead foil screens
3. 7.5 cm (3 in.), 400 kVp, lead foil screens
4. 10 cm (4 in.), 400 kVp, fluorescent screens
5. 12.5 cm (5 in.), 1,000 kVp, lead foil screens
6. 20.5 cm (8 in.), 1,000 kVp, fluorescent screens
7. 20.5 cm (8 in.), 2,000 kVp, lead foil screens
8. 40.5 cm (16 in.), 15-24 MeV, lead foil screens
9. 51 cm (20 in.), 15-24 MeV, fluorescent screens.

LECTURE NO. 11

TITLE: Research Applications of X Rays

PURPOSE: To discuss the uses of x rays in the field of research

TIME: 1 hour

VISUAL AIDS: Blackboard
Slide projector and slides of research installations and procedures

HANDOUTS: None

REFERENCES: Radiation Research

11. RESEARCH APPLICATIONS OF X RAYS

I. INTRODUCTION

X ray is used extensively in the fields of chemistry, biology, medicine, physics, and so forth, for basic and applied research.

II. APPLICATIONS

A. Inducing chemical changes through ionization processes in chemical solutions and compounds

B. Studying cell action after exposure to varying levels and rates of exposure

C. Studying animal growth and structure after various insults

D. Studying fibrous substances

E. Geological studies

F. Medical radiology

LECTURE NO. 12

TITLE: Analytical and Special Industrial Uses of X Rays

PURPOSE: To discuss special industrial uses of x rays

TIME: 1 hour

VISUAL AIDS: Blackboard
Slide projector for selected slides of installations and processes

HANDOUTS: None

REFERENCES: Halmshaw
Physics of Industrial Radiology

12. ANALYTICAL AND SPECIAL INDUSTRIAL USES OF X RAYS

I. INTRODUCTION

X rays are used for numerous analytical applications. These include:

1. Equipment for element analysis
2. Eqipment for thickness gauging
3. Equipment for controlling mixes
4. Equipment for height of fill determinations

II. X-RAY DIFFRACTION AND EMISSION

A. Crystal structure of elements produces distinctive x-ray diffraction patterns

B. Characteristic x-ray emission from elements can be detected

C. Analytical equipment permits determination of elements present in compound without destroying compound

III. THICKNESS GAUGES

A. Exposure rate transmitted through a given material is exponential function of material thickness (fig. 463-31)

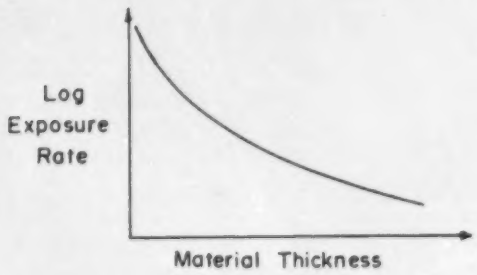


Figure 463-31. Radiation transmission through material.

B. Transmitted exposure rate can be detected and signal used to control final step in rolling process

1. Metal-steel, aluminum, and so forth
2. Paper

C. Thickness gauge therefore part of system

D. Photon energy determined by thickness and type of material

IV. MIXES

A. Combinations of elements or compounds being mixed, for example, cement, can be determined by x-ray analysis during mix

B. Detector signal used to control quantity of each component going into mix

C. Assures consistent product

V. HEIGHT OF FILL SYSTEMS

A. Liquid level in containers must be accurately controlled

1. Under or over filling can cause deterioration of contents or rupture of container
2. Regulations require that content, usually by weight, be as stated on container

B. Glass container liquid level can be determined by light beam transmission through container

1. Small light beam with photodetector can determine over-, normal-, and underfill conditions
2. Light cannot be used when container is opaque, such as metal can

C. X-ray system

1. Small, 0.4 mm (1/64 in.), x-ray beam directed across can line at liquid level corresponding to proper fill height
2. Transmitted x-ray beam exposure rate will be:

a. "High" if can underfilled--no liquid attenuation
b. "Normal" if can properly filled--part of beam attenuated by liquid
c. "Low" if can overfilled--entire x-ray beam attenuated by liquid

3. Two x-ray beams often used

a. One detector beam
b. Second is unattenuated and used as reference source

(1) Detector beam referenced to unattenuated beam
(2) Automatically compensates for any fluctuations in x-ray output

4. Used extensively in canned beverage industry and petroleum industry

VI. OTHER APPLICATIONS

A. Radiography of "works of art"

B. Radiography of stamps, coins, and so forth

C. Sterilization of instruments--electron beam

D. Plastics--electron beam

E. Veterinary radiology

LECTURE 13

TITLE: X-Ray Therapy

PURPOSE: To discuss the use of x rays in the treatment of malignancies

TIME: 1 hour

VISUAL AIDS: Blackboard
Slide projector for selected slides of installations, isodose curves and dose distribution patterns. Overhead projector for selected isodose curves and dose distribution transparencies.

HANDOUTS: None

REFERENCES: Johns and Cunningham
The Physics of Radiology

13. X-RAY THERAPY

I. PURPOSE

Produce desired clinical result without objectionable damage to normal tissue.

II. CLASSIFICATIONS

A. Superficial

1. Conditions at or near body surface

a. 10 - 150 kVp
b. Contact to 50 cm SSD
c. 0 - 1/4 mm Cu total filter

B. Deep

1. Conditions down to body midline

a. 150 - 400 kVp
b. 30 - 100 cm SSD
c. 1/4 - 5 mm Cu total filter

C. Megavoltage

1. Conditions down to body midline

a. 1 MeV and up

(1) 10 - 24 MeV normal maximum

b. 100 cm SSD
c. 3 mm Pb at 1 MeV, 6 mm Pb at 2 MeV

III. TECHNICS

A. Dose distribution versus energy

1. Backscatter
2. Depth dose
3. Isodose curves
4. Integral dose
5. Phantoms

B. Fields

1. Single
2. Multiple
3. Rotation

SECTION II. LABORATORY EXERCISES

GS-463. X-RAY APPLICATIONS

LABORATORY NO. 1

TITLE: X-Ray Film Development

PURPOSE: To study the effect of development time on the finished radiograph

TIME: 3 hours

MATERIALS FOR EACH STUDENT GROUP:

One Teaching X-Ray Unit
One manual x-ray film processing station
One sensitometer
Five sheets of 12.7 x 17.8 cm (5 x 7 in.) Kodak RP Royal x-ray film
Five cardboard exposure holders 12.7 x 17.8 cm (5 x 7 in.)
Five film hangers 12.7 x 17.8 cm (5 x 7 in.)
One MacBeth model TD-102 densitometer
One set of lead letters
One sheet of 3-cycle semi-log graph paper (K&E 46 5493 or equivalent)
Three sheets of linear graph paper (K&E 46 0703 or equivalent)
One ships curve (K&E 1685-48 or equivalent)

REFERENCES:

Eastman Kodak Company
Sensitometric Properties of X-Ray Films

Meredith and Massey
Fundamental Physics of Radiology

Ter-Pogossian
The Physical Aspects of Diagnostic Radiology

LABORATORY NO. 1

1. X-RAY FILM DEVELOPMENT

I. INTRODUCTION

The purpose of this laboratory exercise is to study the effect of development time on the finished radiograph.

Factors which will be investigated include base and fog density, relative speed and average gradient. Fog density is caused by the development of silver bromide crystals that have not been exposed. Radiographic speed is defined as the reciprocal of the exposure necessary to produce a given density. Relative speed is the speed of different films expressed in terms of the speed of one particular film. The average gradient is the slope of the straight line connecting two points on the density versus log exposure curve.

II. EQUIPMENT

A. Teaching X-Ray Unit

B. X-ray film, 12.7 x 17.8 cm (5 x 7 in.), Kodak RP Royal

C. Sensitometer

D. MacBeth Model TD-102 Densitometer

E. Manual x-ray film processing station

F. Cardboard exposure holders

G. Lead letters

III. PROCEDURE

A. Load five cardboard holders with Kodak RP Royal film leaving the protective paper on the film

B. Expose each of the films in the sensitometer using the exposure factors given below. On the sixth step place lead letters to identify your film and the development time to be used

60 kVp
1 mA
2 mm Al added absorber
55 cm source-film distance

Step No.	Exposure Time (sec)
1	1/2
2	1
3	2
4	3
5	5
6	8
7	13
8	20
9	30
10	45
11	60
12	80

C. Processing

1. Load films onto hangers
2. Develop one film each at 20° C (68° F) for:

   a. 1 minute
   b. 3 minutes
   c. 5 minutes
   d. 7 minutes
   e. 25 minutes

3. Rinse all films 1 minute
4. Fix all films 5 minutes
5. Wash all films 15 minutes
6. Dry all films 20 minutes

IV. RESULTS

A. Read and record the density of each step of each film and the unexposed (for base and fog density) portion of each film

B. Plot density versus exposure in mR for each development time on the same sheet of semi-log graph paper. Assume 9.1 mR/mAs.

C. Plot base fog density as a function of development time on linear graph paper

D. Effect of development time on speed

1. Calculate relative speeds at d = 1.5 assigning a relative speed of 100 for 5 minutes development time
2. Relative speed = Exposure at five minutes development/Exposure at X minutes development
3. Plot relative speed (d = 1.5) versus development time on linear graph paper

E. Effect of development time on average gradient

1. Determine the average gradient between d = 1.5 and d = 2.5
2. Average gradient = $\frac{\Delta \text{ density}}{\Delta \log \text{ exposure (mR)}} = \frac{\Delta d}{\log \frac{X_2}{X_1}}$

3. Plot average gradient versus development time on linear graph paper

F. Keep a record of the data obtained for the 5 minute development time as this will be used in a later laboratory.

LABORATORY NO. 1

TYPICAL DATA

Part IV. Results

A. Density versus exposure and development time 60 kVp, 1 mA, 2 mm Al added filtration

Strip No.	mAs	mR	Development time - minutes				
			1	3	5	7	25
			Density				
1	0.5	4.6	0.34	0.35	0.36	0.38	0.46
2	1	9.1	0.46	0.47	0.48	0.49	0.59
3	2	18.2	0.66	0.67	0.69	0.71	0.81
4	3	27.3	0.83	0.85	0.87	0.89	1.00
5	5	45.5	1.11	1.15	1.21	1.25	1.36
6	8	72.8	1.36	1.50	1.59	1.62	1.78
7	13	118	1.65	1.95	2.04	2.06	2.22
8	20	182	1.90	2.31	2.40	2.44	2.58
9	30	273	2.14	2.61	2.70	2.76	2.87
10	45	410	2.32	2.86	2.94	3.00	3.08
11	60	546	2.46	2.98	3.06	3.11	3.16
12	80	728	2.56	3.06	3.15	3.20	3.23
Fog	--	--	0.26	0.27	0.28	0.29	0.36

D. Effect of development time on speed at d = 1.50 assigning a relative speed of 100 for 5 minutes development time

1. 1 minute development
   Relative speed = (7.1) (100)/10 = 71

2. 3 minute development
   Relative speed = (7.1) (100)/8.0 = 89

3. 5 minute development
   Relative speed = (7.1) (100)/7.1 = 100

4. 7 minute development
   Relative speed = (7.1) (100)/6.9 = 103

5. 25 minute development
   Relative speed = (7.1) (100)/5.8 = 123

E. Effect of development time on average gradient for density range 1.5 to 2.5

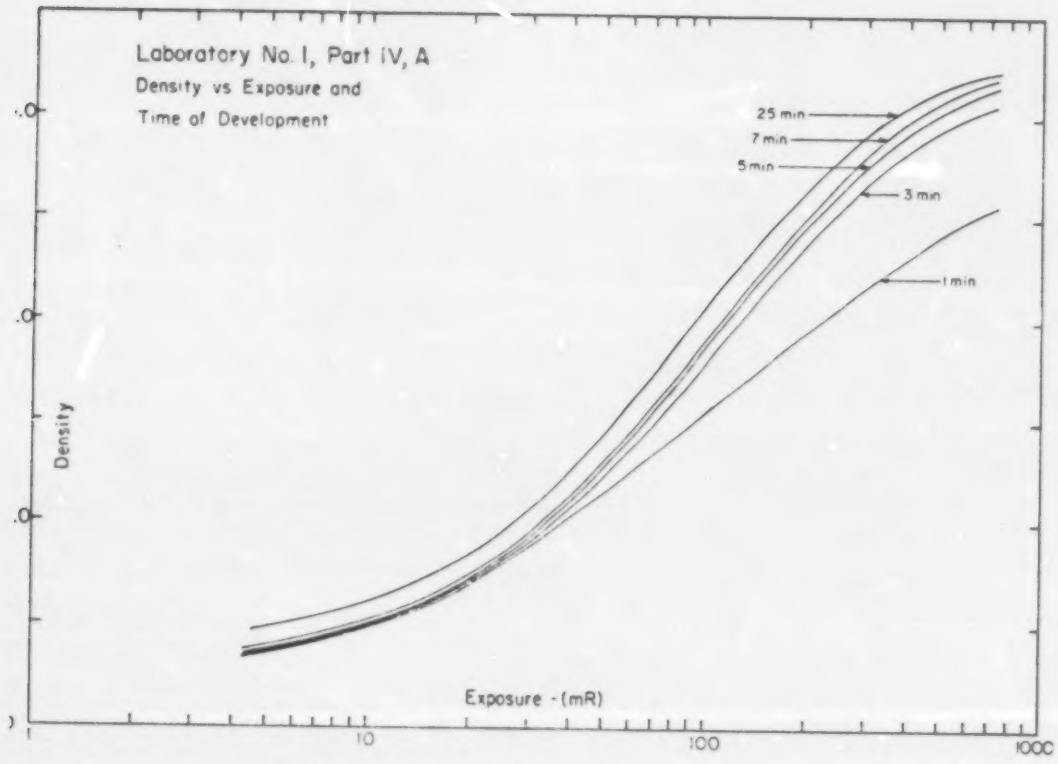
1. 1 minute development
   Average gradient = (2.5 - 1.5)/log 67/10 = 1.21

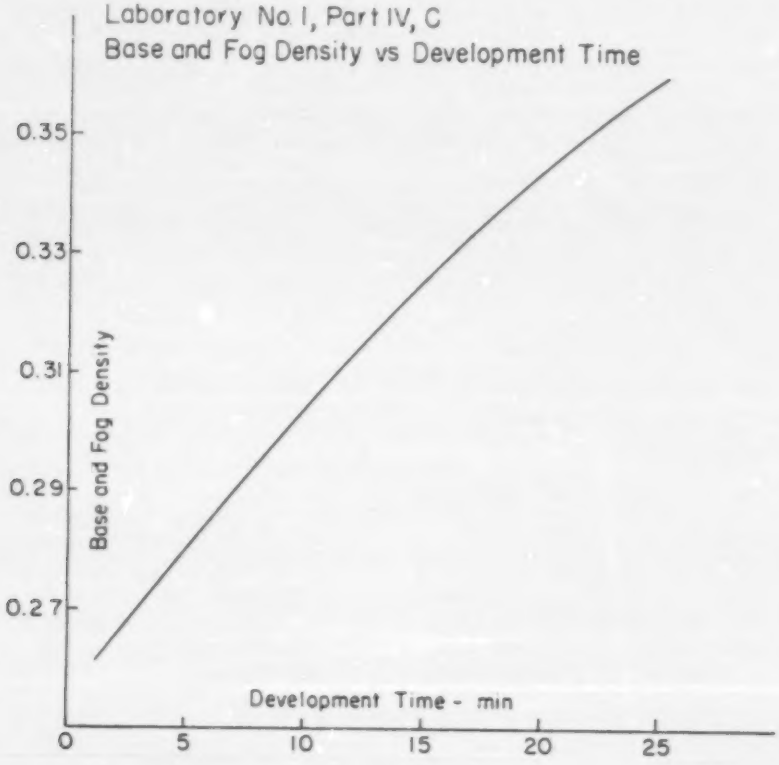
2. 3 minute development
   Average gradient = (2.5 - 1.5)/log 25.6/8.0 = 1.98

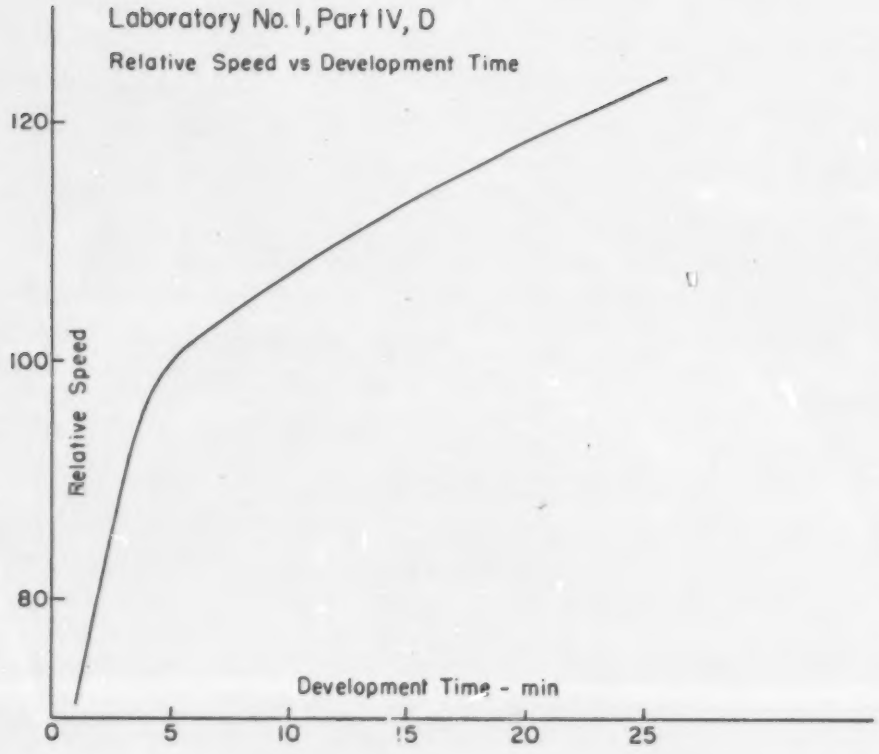
3. 5 minute development
   Average gradient = (2.5 - 1.5)/log 22.8/7.15 = 1.99

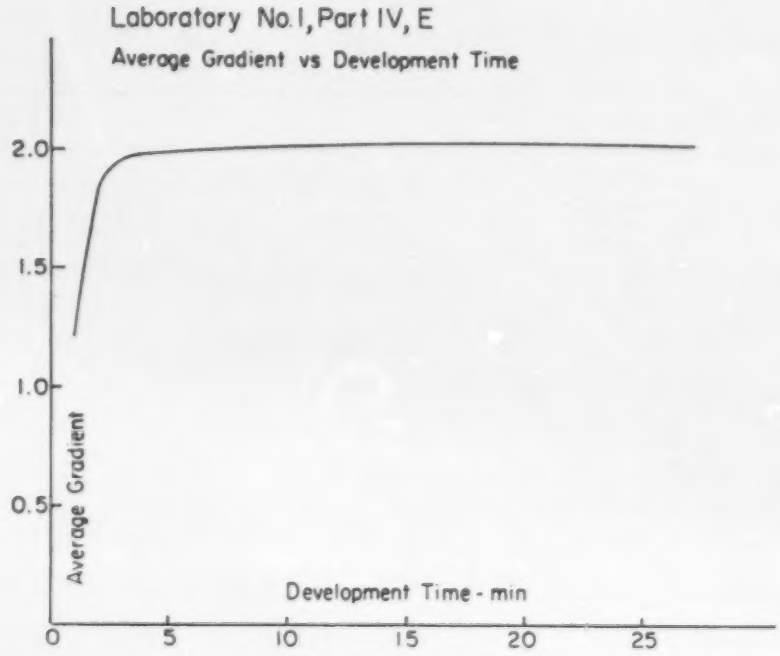
4. 7 minute development
   Average gradient = (2.5 - 1.5)/log 21.5/6.8 = 2.00

5. 25 minute development
   Average gradient = (2.5 - 1.5)/log 18/5.8 = 2.03


Laboratory No. I, Part IV, A
Density vs Exposure and
Time of Development
25 min
7 min
5 min
3 min
1 min
Density
Exposure - (mR)
10
100
1000


Laboratory No. I, Part IV, C
Base and Fog Density vs Development Time
0.35
0.33
0.31
0.29
0.27
Base and Fog Density
Development Time - min
0
5
10
15
20
25


Laboratory No. I, Part IV, D
Relative Speed vs Development Time
120
100
80
Relative Speed
Development Time - min
0
5
10
15
20
25


Laboratory No. I, Part IV, E
Average Gradient vs Development Time
2.0
1.5
1.0
0.5
Average Gradient
Development Time - min
0
5
10
15
20
25

LABORATORY NO. 2

TITLE: Sensitometric Properties of Direct Exposure X-Ray Film

PURPOSE: To take data, plot, and study characteristic curves of various direct exposure x-ray films

TIME: 3 hours

MATERIALS FOR EACH STUDENT GROUP:

One Teaching X-Ray Unit
One Sensitometer
One manual x-ray film processing station
One 12.7 x 17.8 cm (5 x 7 in.) sheet of each type of film to be studied:
- Kodak Type RP/M
- Kodak Type AA
- Kodak No Screen

Three cardboard exposure holders 12.7 x 17.8 cm (5 x 7 in.)
Three film hangers 12.7 x 17.8 cm (5 x 7 in.)
One MacBeth model TD-102 densitometer
Lead Letters
One sheet four cycle semi-log paper
One ships curve

REFERENCES:

Eastman Kodak Company
Industrial Radiography

Eastman Kodak Company
Sensitometric Properties of X-Ray Film

Meredith and Massey
Fundamental Physics of Radiology

Ter-Pogossian
The Physical Aspects of Diagnostic Radiology

LABORATORY NO. 2

2. SENSITOMETRIC PROPERTIES OF DIRECT EXPOSURE X-RAY FILM

I. INTRODUCTION

The purpose of this laboratory exercise is to take data, plot, and study the characteristic curves of various direct exposure x-ray films.

II. EQUIPMENT

A. Teaching X-Ray Unit

B. X-ray film 12.7 x 17.8 cm (5 x 7 in.)

1. Kodak Type RP/M
2. Kodak Type AA
3. Kodak No Screen (Medical)

C. MacBeth Model TD-102 densitometer

D. Sensitometer

E. Cardboard exposure holders

F. Manual x-ray film processing station

G. Set of lead identifying letters

III. PROCEDURE

A. Load one cardboard holder for each film type

B. Expose each of the films in the sensitometer using the exposure factors given below. On the sixth step place lead letters to identify your film and the film type.

60 kVp

1 mA

2 mm Al added absorber

55 cm source-film distance

Step No.	Exposure Time (Seconds) Type AA	Type RP/M	No Screen
1	1	6	1/6
2	2	10	7/20
3	4	14	1/2
4	6	20	4/5
5	10	30	1-1/4
6	14	40	2
7	20	50	3
8	25	70	4
9	35	90	5
10	45	120	6
11	55	150	8
12	65	200	10

C. Processing

1. Develop for 5 minutes (agitate) at 20° C (68° F)
2. Rinse for 1 minute
3. Fix for 5 minutes (agitate)
4. Wash for 15 minutes
5. Dry for 20 minutes

D. Read and record the density of each strip and the unexposed portion of the film

E. Plot net density versus exposure in mR for each film type on the same sheet of semi-log graph paper. Assume 9.1 mR/mAs

IV. PROBLEMS (Show all calculations)

A. Find the average gradient of each film for the density range 0.5 - 2.5

B. Find the relative speed of each film at d = 1.5 assuming Type AA has a relative speed of 100 at d = 1.5

LABORATORY NO. 2

TYPICAL DATA

Part III. D. Density versus exposure

Step No.	Type AA mAs	Type AA Gross Density	Type AA Net	RP/M mAs	RP/M Gross Density	RP/M Net	No Screen mAs	No Screen Gross Density	No Screen Net
1	1	.22	.05	6	.25	.09	.167	.31	.05
2	2	.30	.13	10	.34	.18	.35	.39	.13
3	4	.42	.25	14	.43	.27	.5	.46	.20
4	6	.55	.38	20	.57	.41	.8	.63	.37
5	10	.81	.64	30	.79	.63	1.25	.86	.60
6	14	1.07	.90	40	98	.82	2.00	1.24	.98
7	20	1.46	1.29	50	1.17	1.01	3.00	1.66	1.40
8	25	1.79	1.62	70	1.56	1.40	4.00	2.14	1.88
9	35	2.35	2.18	90	2.00	1.84	5.00	2.54	2.28
10	45	2.85	2.58	120	2.63	2.47	6.00	2.74	2.48
11	55	3.36	3.19	150	3.12	2.96	8.00	3.46	3.20
12	65	3.78	3.61	200	3.90	3.74	10.00	4.00	--
Fog	--	0.17	--	--	0.16	--	--	0.26	--

Part IV. Problems

A. Average gradient for d = 0.5 - 2.5

1. No Screen $\bar{G}$ = (2.5 - 0.5)/log 5.7/1.1 = 2.0/.714 = 2.80

2. Type AA $\bar{G}$ = (2.5 - 0.5)/log 40.6/7.9 = 2.0/.712 = 2.81

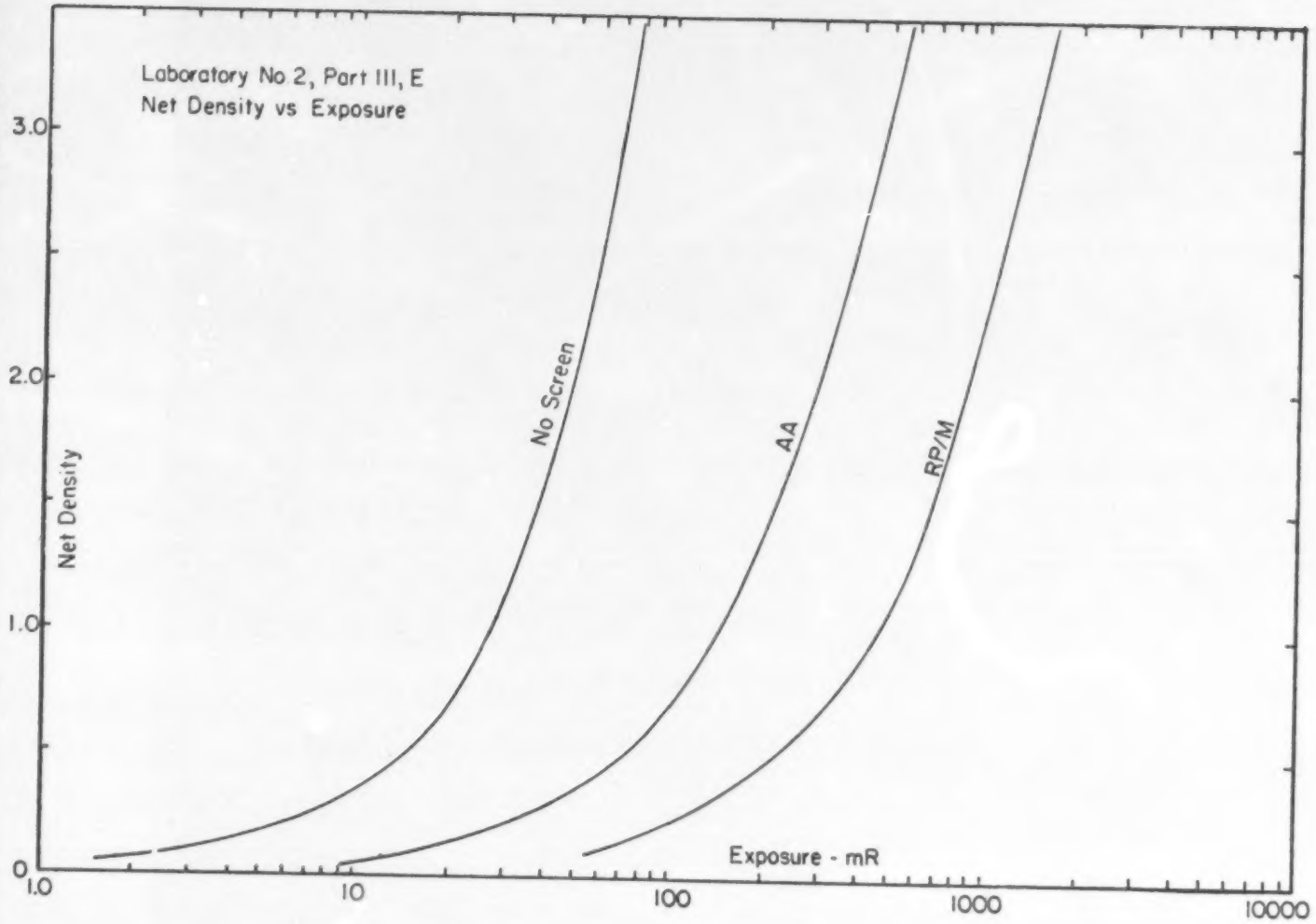
3. RP/M $\bar{G}$ = (2.5 - 0.5)/log 123/24.5 = 2.0/.702 = 2.85

B. Relative speed at d = 1.5 assuming AA has a relative speed of 100 at d = 1.5

1. No screen relative speed = (23.3) (100)/3.15 = 740

2. Type AA relative speed = (23.3) (100)/23.3 = 100

3. RP/M relative speed = (23.3) (100)/74 = 31.5


Laboratory No 2, Part III, E
Net Density vs Exposure
Net Density
3.0
2.0
1.0
0
No Screen
AA
RP/M
Exposure - mR
1.0
10
100
1000
10000

LABORATORY NO. 3

TITLE: Sensitometric Properties of Medical X-Ray Film

PURPOSE: To take data, plot, and study characteristic curves of various medical x-ray film-screen combinations

TIME: 3 hours

MATERIALS FOR EACH STUDENT GROUP:

One Teaching X-Ray Unit
One Sensitometer
Four 12.7 x 17.8 cm (5 x 7 in.) sheets of each type of film to be studied:
- Kodak RP Royal
- Kodak RP

Two 12.7 x 17.8 cm (5 x 7 in.) cardboard film holders
Two of each of the following 12.7 x 17.8 cm (5 x 7 in.) cassettes:
- High Speed
- Par Speed
- Detail

One set lead letters
One Kodak X-Omat automatic x-ray film processor
One MacBeth model TD-102 densitometer
Two sheets of three cycle semi-log paper
One ships curve

REFERENCES:

DuPont Company
The Care and Use of Cronex X-tra Life Intensifying Screens

Eastman Kodak Company
Sensitometric Properties of X-Ray Films

LABORATORY NO. 3

3. SENSITOMETRIC PROPERTIES OF MEDICAL X-RAY FILM

I. INTRODUCTION

The purpose of this laboratory exercise is to take data, plot, and study the characteristic curves of various medical x-ray film-screen combinations.

II. EQUIPMENT

A. X-ray film 12.7 x 17.8 cm (5 x 7 in.)

1. Kodak RP Royal
2. Kodak RP

B. Teaching X-Ray Unit with sensitometer

C. Film cassettes 12.7 x 17.8 cm (5 x 7 in.)

1. Hi-speed
2. Par Speed
3. Detail
4. Cardboard

D. MacBeth Model TD-102 densitometer

E. Kodak X-Omat automatic x-ray film processor

F. Lead letters

III. PROCEDURE

A. Load one cassette for each film-screen combination to be studied

B. Expose each of the films in the sensitometer using the exposure factors given below. Use the lead letters to identify your films.

1. X-ray machine settings for film-screen combinations:

60 kVp
1 mA
0.5 mm Cu added absorber
55 cm source-film distance
0.5 mR/mAs

Step No.	Exposure Time (sec.) RP Film Hi	Par	Detail	RP Royal Film Hi	Par	Detail
1	2/5	1/2	1-1/2	1/4	3/10	1
2	3/5	4/5	2-1/2	2/5	1/2	1-1/2
3	1	1	4	3/5	4/5	2
4	1-1/2	1-1/2	6	4/5	1	3
5	2	2	9	1-1/4	1-1/2	6
6	3	3	12	2	2	10
7	4	4	15	3	3	15
8	6	6	25	4	4	20
9	10	9	35	6	6	30
10	15	12	50	10	10	50
11	20	20	70	15	15	70
12	30	40	100	25	25	100

2. X-ray machine setting for medical films with no screens:

60 kVp
1 mA
2 mm Al added absorber
55 cm source-film distance
9.1 mR/mAs

Step No.	Exposure Time (sec.) RP Royal	RP
1	1/2	1
2	1	2
3	2	3
4	3	5
5	5	8
6	8	13
7	13	20
8	20	30
9	30	40
10	45	55
11	60	70
12	80	90

C. Process the films using the automatic processor. Three 12.7 x 17.8 cm (5 x 7 in.) films can be processed together.

D. Read the density of each step and the unexposed (for base and fog density) portion of the film.

E. Plot net density versus exposure in mR for each film-screen combination on the same sheet of semi-log graph paper. On a second sheet of semi-log paper, plot net density versus exposure in mR for the two films exposed without screens.

IV. PROBLEMS (Show All Calculations)

A. Find the average gradient of each film-screen combination and each direct exposure film for the density range 0.5 - 2.0.

B. Find the relative speed of each film-screen combination at density 1.0 assuming the RP-Par Speed combination has a relative speed of 100 at a density of 1.0.

C. Find the relative speed of the films which were exposed directly to x rays at density 1.5 assuming Type AA has a relative speed of 100 at a density of 1.5 (use the results from Laboratory No. 2).

LABORATORY NO. 3

TYPICAL DATA

PART III. B. Density versus exposure, film-screen combinations

1. RP Film

Step No.	Hi Speed			Par Speed			Detail		
	mAs	Gross Density	Net	mAs	Gross Density	Net	mAs	Gross Density	Net
1	0.4	.24	.04	0.5	.22	.02	1.5	.22	.02
2	0.6	.30	.10	0.8	.30	.10	2.5	.26	.06
3	1.0	.54	.34	1.0	.38	.18	4.0	.36	.16
4	1.5	.87	.67	1.25	.61	.41	6.0	.52	.32
5	2.0	1.18	.98	2.0	.90	.70	9.0	.80	.60
6	3.0	1.68	1.48	3.0	1.31	1.11	12.0	1.10	.90
7	4.0	2.16	1.96	4.0	1.68	1.48	15.0	1.36	1.16
8	6.0	2.62	2.42	6.0	2.17	1.97	25.0	1.98	1.78
9	10.0	3.04	2.84	9.0	2.58	2.38	35.0	2.37	2.17
10	15.0	3.22	3.02	12.0	2.83	2.63	50.0	2.67	2.47
11	20.0	3.29	3.09	20.0	3.13	2.93	70.0	2.90	2.70
12	30.0	3.37	3.17	40.0	3.34	3.14	100.0	3.07	2.87
Fog	--	0.20	--	--	0.20	--	--	0.20	--

PART III. B.2. RP Royal Film

Step No.	Hi Speed			Par Speed			Detail		
	mAs	Gross Density	Net	mAs	Gross Density	Net	mAs	Gross Density	Net
1	.25	.30	.07	.3	.27	.04	1.0	.26	.03
2	.4	.43	.20	.5	.40	.17	1.5	.32	.09
3	.6	.72	.49	.8	.74	.51	2.0	.40	.17
4	.8	.98	.75	1.0	.93	.70	3.0	.58	.35
5	1.25	1.52	1.29	1.5	1.37	1.14	6.0	1.13	.90
6	2.0	2.05	1.82	2.0	1.74	1.51	10.0	1.71	1.48
7	3.0	2.49	2.26	3.0	2.21	1.98	15.0	2.20	1.97
8	4.0	2.74	2.51	4.0	2.52	2.29	20.0	2.48	2.25
9	6.0	3.03	2.80	6.0	2.85	2.62	30.0	2.77	2.54
10	10.0	3.24	3.01	10.0	3.12	2.89	50.0	3.04	2.81
11	15.0	3.34	3.11	15.0	3.26	3.03	70.0	3.18	2.95
12	25.0	3.46	3.23	25.0	3.34	3.11	100.0	3.30	3.07
Fog	--	0.23	--	--	0.23	--	--	0.23	--

PART III.B Density versus exposure, direct exposures

Step No.	RP			RP Royal		
	mAs	Gross	Net	mAs	Gross	Net
1	1	.34	.09	0.5	.36	.08
2	2	.47	.22	1.0	.45	.17
3	3	.60	.35	2.0	.67	.39
4	5	.83	.58	3.0	.85	.57
5	8	1.11	.86	5.0	1.16	.88
6	13	1.47	1.22	8.0	1.54	1.26
7	20	1.91	1.66	13.0	2.01	1.73
8	30	2.36	2.11	20.0	2.40	2.12
9	40	2.64	2.39	30.0	2.76	2.48
10	55	2.94	2.69	45.0	3.07	2.79
11	70	3.11	2.86	60.0	3.21	2.93
12	90	3.26	3.01	80.0	3.30	3.02
Fog	--	0.25	--	--	0.28	--

PART IV. Problems

A. Average gradient for d = 0.5 - 2.0

1. RP film, Hi-Speed screens
   $\bar{G}$ = (2.0 - 0.5)/log 4.2/1.25 = 1.5/.527 = 2.84

2. RP film Par Speed screens
   $\bar{G}$ = (2.0 - 0.5)/log 6.15/1.65 = 1.5/.572 = 2.62

3. RP film, Detail screens
   $\bar{G}$ = (2.0 -0.5)/log 30/7.9 = 1.5/.58 = 2.59

4. RP Royal film, Hi-Speed screens
   $\bar{G}$ = (2.0 - 0.5)/log 2.3/0.63 = 1.5/.563 = 2.67

5. RP Royal film, Par Speed screens
   $\bar{G}$ = (2.0 - 0.5)/log 3.05/0.81 = 1.5/.577 = 2.60

6. RP Royal film, Detail screens
   $\bar{G}$ = (2.0 - 0.5)/log 15.5/3.7 = 1.5/.617 = 2.43

7. RP film, cardboard holder
   $\bar{G}$ = (2.0 - 0.5)/log 27.5/4.25 = 1.5/.811 = 1.85

8. RP Royal film, cardboard holder
   $\bar{G}$ = (2.0 - 0.5)/log 17.1/2.55 = 1.5/.828 = 1.81

PART IV. B. Relative speed of film-screen combinations at d = 1.0 assuming the Blue Brand film, Par Speed screen combination relative speed = 100 d = 1.00

1. RP film, Hi-Speed screens
   Relative speed = (2.68) (100)/2.05 = 131

2. RP film, Par Speed screens
   Relative speed = (2.68) (100)/2.68 = 100

3. RP film, Detail screens
   Relative speed = (2.68) (100)/13.2 = 20.3

4. RP Royal film, Hi-Speed screens
   Relative speed = (2.68) (100)/1.0 = 268

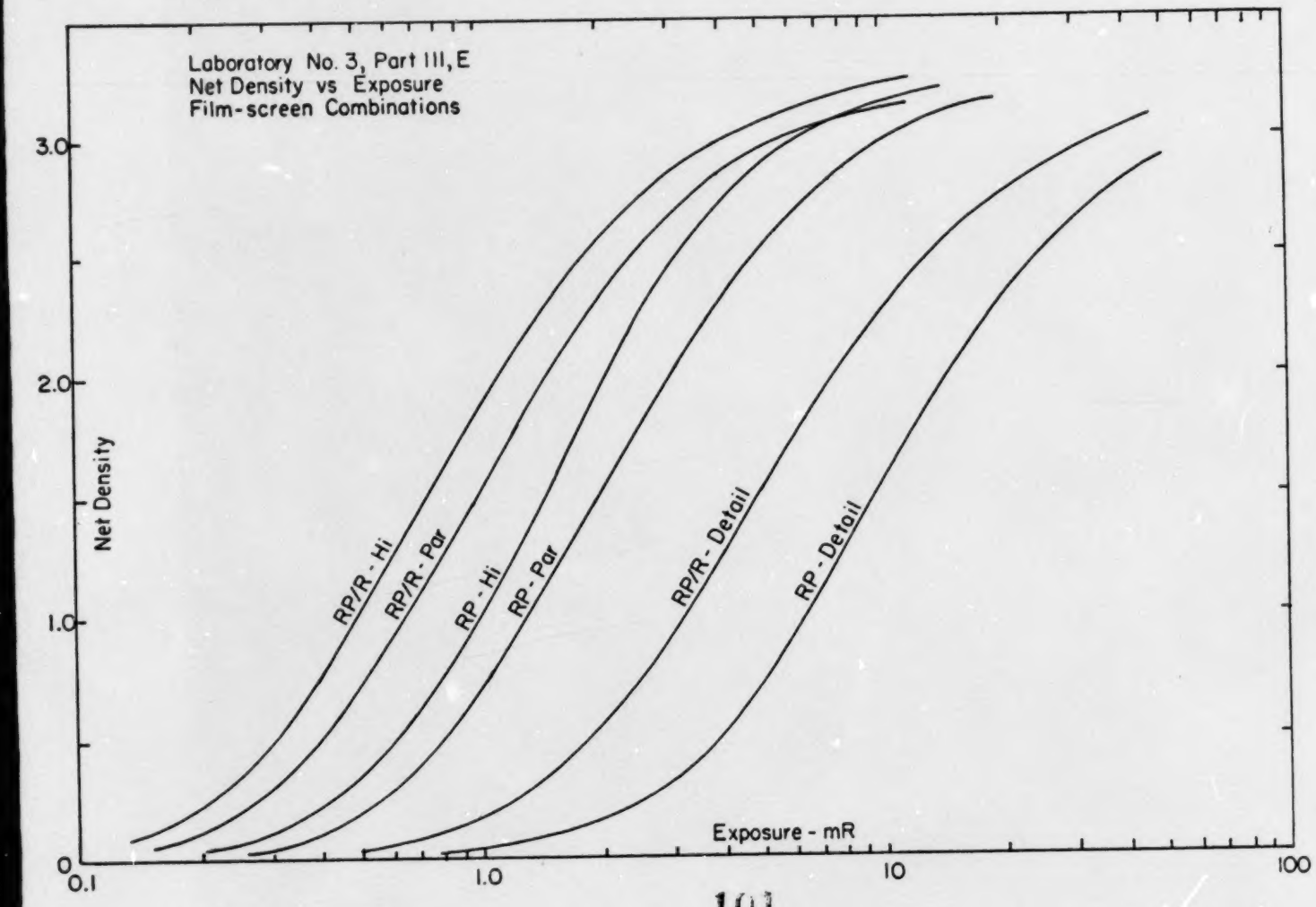
5. RP Royal film, Par Speed screens
   Relative speed = (2.68) (100)/1.31 = 205

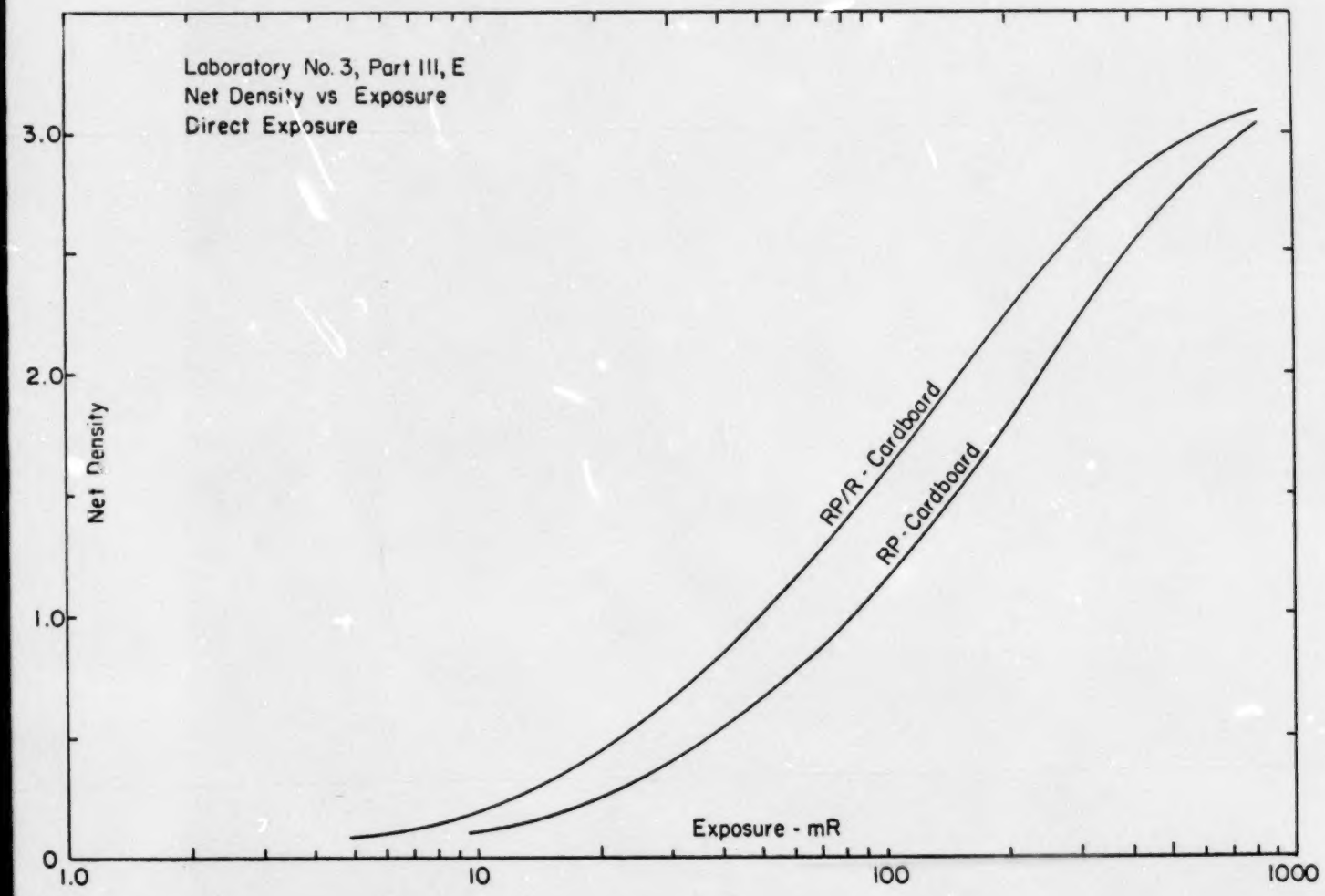
6. RP Royal film, Detail screens
   Relative speed = (2.68) (100)/6.6 = 40.6

C. Relative speed of direct exposures at d = 1.5 using type AA (Laboratory No. 2) relative speed = 100 at d = 1.5

1. RP film
   Relative speed = (23.3) (100)/17.0 = 137

2. RP Royal film
   Relative speed = (23.3) (100)/10.2 = 228


Laboratory No. 3, Part III, E
Net Density vs Exposure
Film-screen Combinations
Net Density
3.0
2.0
1.0
0
0.1
1.0
10
100
Exposure - mR
RP/R - Hi
RP/R - Par
RP - Hi
RP - Par
RP/R - Detail
RP - Detail


Laboratory No. 3, Part III, E
Net Density vs Exposure
Direct Exposure
3.0
2.0
1.0
0
Net Density
RP/R - Cardboard
RP - Cardboard
Exposure - mR
1.0
10
100
1000

LABORATORY NO. 4

TITLE: Introduction to Radiography

PURPOSE: The purpose of this laboratory exercise is to introduce the student to the principles of medical radiography

TIME: 3 hours

MATERIALS FOR EACH STUDENT GROUP:

One teaching X-Ray Unit
One Radiographic Test Block
Three 12.7 x 17.8 cm (5 x 7 in.) cardboard film holders
Two 12.7 x 17.8 cm (5 x 7 in.) Par Speed screen cassettes
Three sheets 12.7 x 17.8 cm (5 x 7 in.) Kodak Type RP/M x-ray film
Two sheets 12.7 x 17.8 cm (5 x 7 in.) Kodak RP x-ray film
One set lead numbers and letters
One Kodak X-OMAT x-ray film processor
One 35.6 x 43.2 cm (14 x 17 in.) illuminator
One MacBeth model TD-102 densitometer

REFERENCES: Bloom, Hollenbach and Morgan
Medical Radiographic Technic

Trout
Teaching X-Ray Unit

LABORATORY NO. 4

4. INTRODUCTION TO RADIOGRAPHY

I. INTRODUCTION

The purpose of this laboratory exercise is to study the effect of kilovoltage, x-ray film type and intensifying screens on film contrast, latitude and definition. The Radiographic Test Block used contains a tooth (with filling), bone, water, fat and air enclosed in a 1.9 cm thick Plexiglas® block and represents the range of material densities normally found in the human body.

II. EQUIPMENT

A. Teaching X-Ray Unit

B. Radiographic Test Block

C. Cardboard film holders

D. Par Speed screen cassettes

E. Kodak type RP/M x-ray film

F. Kodak RP x-ray film

G. Lead letters and numbers

H. Kodak X-OMAT automatic x-ray film processor

I. Illuminator

J. MacBeth model TD-102 densitometer

III. PROCEDURE

A. Preparations

1. Load three 12.7 x 17.8 cm (5 x 7 in.) cardboard film holders with 12.7 x 17.8 cm (5 x 7 in.) Kodak Type RP/M x-ray film
2. Load two 12.7 x 17.8 cm (5 x 7 in.) Par Speed screen cassettes with 12.7 x 17.8 cm (5 x 7 in.) Kodak RP x-ray film

B. Radiography, RP film, Par speed screen cassette, 40 kVp

1. Set up the x-ray machine as follows:

a.	kVp	40
b.	mA	1.0
c.	Added filter	None
d.	Added diaphragm	None

2. Center a 12.7 x 17.8 cm (5 x 7 in.) Par Speed screen cassette on the floor of the enclosure with the 17.8 cm (7 in.) dimension front to back in the enclosure. Center the Radiographic Test Block on the cassette with the section containing the tooth to the front. Place a small (2.5 x 2.5 cm) lead beam blocker on the cassette and lead letters and numbers to identify the radiograph.
3. Make an exposure totaling 7/10 second (36 impulses plus 6 impulses)
4. Remove the cassette from the enclosure

C. Radiography, RP film, Par Speed screen cassette, 100 kVp

1. Set up the x-ray machine as follows:

a.	kVp	100
b.	mA	1.0
c.	Added filter	1.5 mm Al
d.	Added diaphragm	None

2. Using the second Par Speed screen cassette, position and identify the film as in III.B.
3. Make a 2/15 second (8 impulses) exposure
4. Remove the cassette from the enclosure

D. Radiography, Type RP/M film, cardboard film holder, 40 kVp

1. Set up the x-ray machine as follows:

a.	kVp	40
b.	mA	1.0
c.	Added filter	None
d.	Added diaphragm	None

2. Center a 12.7 x 17.8 cm (5 x 7 in.) cardboard film holder on the floor of the enclosure with the 17.8 cm (7 in.) dimension front to back in the enclosure. Center the Radiographic Test Block on the film holder with the section containing the tooth to the front. Place the lead beam blocker and lead letters and numbers on the film holder to identify your radiograph.
3. Make a 90-second exposure
4. Remove the cardboard film holder from the enclosure

E. Radiography, Type RP/M film, cardboard film holder, 100 kVp

1. Set up the x-ray machine as follows:

a.	kVp	100
b.	mA	1.0
c.	Added filter	None
d.	Added diaphragm	None

2. Using a second cardboard film holder position the film holder and Radiographic Test Block and use the beam blocker and lead letters as in III.D.
3. Make a 9-second exposure
4. Remove the film holder from the enclosure

F. Effect of object-film distance

1. Set up the x-ray machine as follows:

a.	kVp	40
b.	mA	1.0
c.	Added filter	None
d.	Added diaphragm	None

2. Center the third cardboard film holder with Type RP/M film on the floor of the enclosure as before
3. Place the Radiographic Test Block on its aluminum support frame. Center the frame on the cassette and make a 90-second exposure.
4. Remove the film holder from the enclosure

G. Film Processing

1. Process the films in the automatic processor
2. Three 12.7 x 17.8 cm (5 x 7 in.) films can be processed at one time.

IV. FILM DENSITY MEASUREMENTS

A. Measure and record the section densities for the four films in Parts III.B, C, D and E

B. Measure and record the base fog densities (film area under the lead beam blocker) for the four films in Part III. B, C, D and E

C. The section densities should be measured in the center of the tooth and bone and in the center of the other sections

D. Determine and record the net density for each section

V. QUESTIONS

A. How does kilovoltage affect film density and latitude? Describe in detail referring to the data in Part IV.

B. What is the effect of film and film-screen combinations on detail? Describe, referring to the films in Parts III. B, C, D and E.

C. What is the effect of object-film distance on magnification and detail? Describe, referring to the films in Parts III. D and F.

LABORATORY NO. 4

TYPICAL DATA

PART IV. Film density measurements

kVp	Film	Holder	Part				
			Air	Fat	Water	Bone	Tooth
			Gross Density				
40	RP	Screen	1.95	1.45	1.14	0.91	0.28
100	RP	Screen	1.79	1.43	1.34	1.27	0.55
40	RP/M	Cardboard	1.98	1.33	1.03	0.87	0.32
100	RP/M	Cardboard	1.67	1.33	1.19	1.11	0.54

Base fog: RP 0.25
RP/M 0.17

PART V. Questions

A. Increasing kilovoltage decreases radiographic contrast and increases latitude. For a constant density at the section containing the water, the density at the air and fat sections decrease as kilovoltage increases and the densities at the bone and tooth sections increase as kilovoltage increases.

B. There is a loss of detail with the film-screen combination as compared to the direct exposure. This is evident, in particular, in the fine structures of the bone and is due to the coarser film grain and screen mottle with the film-screen combination.

C. Increasing object-film distance increases magnification and decreases sharpness (because of increased penumbra).

LABORATORY NO. 5

TITLE: Medical and Dental Radiography

PURPOSE: To radiograph selected body parts imbedded in tissue equivalent material

TIME: 6 hours

MATERIAL FOR EACH STUDENT GROUP:

One GE DXS-350 X-Ray Unit with GE Monarch Radiographic Table
One GE CMX-110 Battery Powered Mobile X-Ray unit with GE Horizontal Bucky Table
One GE 100 Dental X-Ray Unit
One vertical cassette holder
One Kodak X-OMAT automatic x-ray film processor
One manual x-ray film processing station
20.3 x 25.4 cm (8 x 10 in.) cardboard exposure holders as required
Cassettes with Par Speed intensifying screens as required
20.3 x 25.4 cm (8 x 10 in.)
25.4 x 30.5 cm (10 x 12 in.)
35.6 x 43.2 cm (14 x 17 in.)
Kodak RP medical x-ray film as required
20.3 x 25.4 cm (8 x 10 in.)
25.4 x 30.5 cm (10 x 12 in.)
35.6 x 43.2 cm (14 x 17 in.)
Kodak 20.3 x 25.4 cm (8 x 10 in.) No-Screen medical x-ray film as required
Kodak Radia-tized and Ultra-Speed periapical dental x-ray film as required
One 3M human phantom (foot, hand, torso, chest, skull and dental half-skull)
One set lead letters and numbers

REFERENCES:

Bloom, Hollenback and Morgan
Medical Radiographic Technic

Greenfield and Cooper
Manual of Radiographic Positioning

General Electric
How to Prepare a Technic Chart

Wuehrmann and Manson-Hing
Dental Radiology

LABORATORY NO. 5

5. MEDICAL AND DENTAL RADIOGRAPHY

I. INTRODUCTION

The purpose of this laboratory exercise is to radiograph various body phantom parts.

II. EQUIPMENT

A. X-Ray machines

1. GE DXS-350
2. GE CMX-110 X-Ray Unit
3. GE-100 Dental

B. Kodak X-OMAT automatic x-ray film processor

C. Manual x-ray film processing station

D. Kodak RP, No-Screen and dental x-ray film

E. Cardboard exposure holders

F. Cassettes with Par Speed screens

G. 3M human phantom

H. Lead letters and numbers

I. Vertical cassette holder

III. PROCEDURE

Make radiographs using the suggested exposure values. Use lead letters to identify your film and the radiographic technic. View each radiograph with the instructor. If the radiograph is not of the correct density, revise the exposure (mAs) using the sensitometric curves for the film or film-screen combination (data from Laboratories 2 and 3) and make another radiograph. If the part is not positioned properly for the radiographic view, reposition the part and make another radiograph. A book on positioning will be supplied by the instructor.

A. Suggested exposure values

View/Part	kVp	SFD-cm	Film	Grid	mAs	
					No Screens	Screens
P.A. Hand	60	100	No Screen/RP	No	12	1.5
A.P. Foot	60	100	No Screen/RP	No	24	3
A.P. Ankle	60	100	No Screen/RP	No	48	5
Lateral Ankle	60	100	No Screen/RP	No	40	5
A.P. Pelvis	70	100	RP	12:1	--	100
Lateral Lumbar Spine	86	100	RP	12:1	--	200
Lateral Lumbar Spine	66	100	RP	12:1	--	1000
A.P. Dorsal Spine	70	100	RP	12:1	--	80
Lateral Dorsal Spine	86	100	RP	12:1	--	25
Lateral Skull	86	100	RP	12:1	--	20
Lateral Mastoid	86	100	RP	12:1	--	30
P.A. Skull	86	100	RP	12:1	--	60
P.A. Chest	80	183	RP	No	--	10
First Molar	90	20	Radia-Tized	No	9	--
First Molar	65	20	Radia-Tized	No	27.5	--
First Molar	90	20	Ultra-Speed	No	1.5	--
First Molar	65	20	Ultra-Speed	No	5	--

B. Extremities

1. Use 20.3 x 25.4 cm (8 x 10 in.) film

    a. No-Screen film with cardboard exposure holder
    b. RP film with Par Speed screen cassette

2. Use the CMX-110 Mobile X-Ray Unit
3. Positioning

    a. P.A. hand: center distal end of third metacarpal bone over center of film holder and at central beam
    b. A.P. foot: center proximal end of second metatarsal on film. Tilt tube 15° toward patient's head and 15° toward medial side of foot.
    c. A.P. ankle: center midway between mallevli
    d. Lateral ankle: center at internal malleolus

C. Trunk

1. Use 35.6 x 43.2 cm (14 x 17 in.) RP film with a Par Speed screen cassette
2. Use the DXS-350
3. Positioning

    a. A.P. pelvis: center on median line halfway between superior margin of public symphysis and line drawn through anterior superior iliac spines. Use gonad shielding.
    b. Lateral lumbar spine: center on line drawn between first lumbar and junction of fifth lumbar and sacrum with central beam perpendicular to this line.
    c. A.P. dorsal spine: use table in vertical position. Center on median line halfway between superior border of manubrium and inferior tip of xyphoid process.

d. P.A. chest: use the vertical cassette holder. Locate acromiom processes 5 - 7.5 cm below upper corner of cassette. Center central beam at center of cassette.

D. Skull

1. Use 20.3 x 25.4 cm (8 x 10 in.) RP film with a Par Speed screen cassette
2. Use the DXS-350
3. Positioning

   a. Lateral skull: center at midpoint between glabella and occipital protuberance
   b. P.A. skull: position skull on forehead and nose with line between outer canthus of eye and external auditory meatus perpendicular to tabletop. Center film laterally to outer canthus of eye and central beam to center of film.
   c. Lateral mastoid (right): place right external auditory meatus at center of film. Tilt tube 15° toward neck with central beam directed at center of film. Use a field size at the film of 10 x 10 cm.

E. Dental

1. Use periapical film, Radia-tized and Ultra-Speed
2. Use the Dental 100
3. Positioning

   a. Place the film in the oral cavity and hold in place using the spring-loaded film holder attached to the phantom base
   b. Center the x-ray beam on the film with the central beam perpendicular to the film

IV. RESULTS

A. Prepare a table listing the exposure factors used to obtain your final radiographs

B. Turn in to the instructor your final radiographs along with the exposure factor table.

LABORATORY NO. 6

TITLE: Industrial Radiography

PURPOSE: To develop techniques for radiography of selected industrial specimens

TIME: 3 hours

MATERIAL FOR EACH STUDENT GROUP:

One G.E. Maxitron 300 X-Ray Unit
One Teaching X-ray Unit
One Kodak X-OMAT film processor
Kodak Industrial X-Ray film 20.3 x 25.4 cm (8 x 10 in.) as required
Cardboard film holders, 20.3 x 25.4 cm (8 x 10 in.) as required
Cassettes, 20.3 x 25.4 cm (8 x 10 in.) with 0.0125 cm (0.005 in.) lead screens as required
One MacBeth model TD-102 densitometer
One industrial radiograph illuminator
Selected industrial specimens (magnesium, aluminum, steel castings and welded plates)
Selected industrial penetrameters
Set lead letters and numbers

REFERENCES:

Eastman Kodak Company
Radiography in Modern Industry

Halmshaw
Physics of Industrial Radiology

LABORATORY NO. 6

6. INDUSTRIAL RADIOGRAPHY

I. INTRODUCTION

The purpose of this laboratory exercise is to develop a technic chart for the radiography of selected specimens.

II. MATERIALS AND EQUIPMENT

A. Teaching X-Ray Unit

B. Maxitron 300

C. Kodak X-OMAT automatic film processor

D. Kodak industrial film, 20.3 x 25.4 cm (8 x 10 in.)

E. Cardboard film holders, 20.3 x 25.4 cm (8 x 10 in.)

F. Lead screen cassette, 20.3 x 25.4 cm (8 x 10 in.)

G. MacBeth model TD-102 densitometer

H. Illuminators

I. Selected industrial specimens

J. Industrial penetrameters

K. Lead letters and numbers

III. PROCEDURE

A. Selection of film type

1. Magnesium

a. 0 - 1.25 cm (0 - 1/2 in.) thick, 50 - 100 kVp, Type M
b. 1.25 - 2.5 cm (1/2 - 1 in.) thick, 50 - 90 kVp, Types M or AA
c. 1.25 - 2.5 cm (1/2 - 1 in.) thick, 80 - 100 kVp, Type AA

2. Aluminum

a. 0 - 0.65 cm (0 - 1/4 in.) thick, 50 - 80 kVp, Type M
b. 0 - 0.65 cm (0 - 1/4 in.) thick, 80 - 100 kVp, Type M
c. 0.65 -1.25 cm (1/4 - 1/2 in.) thick, 50 - 80 kVp, Type AA
d. 0.65 - 1.25 cm (1/4 - 1/2 in.) thick, 80 - 100 kVp, Type M
e. 1.25 - 2.5 cm (1/2 - 1 in.) thick, 50 - 80 kVp, Type AA
f. 1.25 - 2.5 cm (1/2 - 1 in.) thick, 80 - 100 kVp, Type M

3. Steel

   a. 0 - 0.65 cm (0 - 1/4 in.) thick, 80 - 100 kVp, Type AA
   b. 0.65 - 1.25 cm (1/4 - 1/2 in.) thick, 80 - 100 kVp, Type AA

B. Radiography of flat-welded plate

1. Obtain two welded plates, one steel and one aluminum, from your instructor
2. Select required films:

   a. Based on thickness and material of specimen
   b. Based on kVp range

3. Select proper penetrameter
4. Make exposures (see III.D. below)

   a. Adjust kVp and mAs to give required sensitivity
   b. Expose at least three films of each plate at different technics to show that selected factors give maximum sensitivity

C. Radiography of castings

1. Obtain one aluminum casting from your instructor
2. Select required film:

   a. Based on thickness and material of specimen
   b. Based on kVp range

3. Make exposure (see III.D. and E. below)

   a. Adjust exposure factors to give a "high quality" radiograph
   b. Expose at least three films at different technics to illustrate why chosen technic is preferred

D. In order to avoid the time involved in manual processing of industrial film, we will use Kodak RP/M medical x-ray film in place of Kodak Type M industrial film in this laboratory exercise.

E. Suggested starting exposures, Teaching X-Ray Unit

1. Welded aluminum plate

   a. Type RP/M film
   b. 80 kVp, 1.0 mA, 30 seconds, no screens
   c. No. 25 penetrameter

2. Aluminum casting No. 1

   a. Type RP/M film
   b. 100 kVp, 1.0 mA, 150 seconds, no screens

3. Aluminum casting No. 2

   a. Type RP/M film
   b. 80 kVp, 1.0 mA, 60 seconds, no screens

F. Suggested starting exposures, Maxitron 300

1. Welded steel plate

a. Type RP/M film
b. 140 kVp, 100 cm SFD, 700 mAs with no screens, 500 mAs, with screens
c. No. 25 penetrameter

2. Aluminum casting No. 1

a. Type RP/M film
b. 100 kVp, 100 cm SFD, 1000 mAs, no screens

IV. RESULTS

A. View all radiographs

B. Identify preferred radiographs and explain preference.

SECTION III. EXAMINATIONS

GS-463. X-RAY APPLICATIONS

GS-463. X-RAY APPLICATIONS

TEST NO. 1

TOTAL GRADE VALUE 110 POINTS

THIS TEST CONSISTS OF TWO PARTS:

PART I

Discussion consists of 7 questions, any 5 of which should be answered.

Grade value--10 points each.

PART II

Discussion consists of 4 questions, any 3 of which should be answered.

Grade value--20 points each.

Name _____

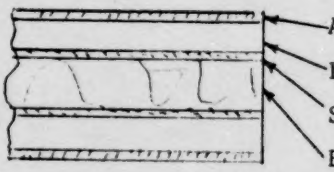
GS-463. X-RAY APPLICATIONS
Test No. 1

PART I

Answer, in the space provided, any 5 of the 7 questions. Grade value--10 points each.

1. Make a cross section drawing of a light sensitive x-ray film. Label and briefly describe each section of the film.

Ans.


Anti abrasion layer. Protects emulsion.
Emulsion. Contains AgBr.
Subbing layer. Bonds emulsion to base.
Base. Supports emulsion.

2. Name three components that make up a typical x-ray film emulsion. What is the purpose of each component?

Ans. a. Gelatin--support for AgBr grains.

b. AgBr--Ag for latent image and developed image formation.

c. Sensitizer--to make AgBr sensitive to latent image formation and thereby susceptible to action of developer.

3. Discuss the effect of temperature and rate of mixing on the size of silver bromide grains.

Ans. a. Fast mix, low temperatue, fine grains.

b. Slow mix, high temperature, coarse grains.

4. What is the reciprocity law as applied to the exposure of x-ray film? When can the reciprocity law fail?

Ans. a. Reciprocity law states that radiographic density is dependent only on the total exposure and not on the exposure rate and exposure time used.

b. The reciprocity law can fail at extremes of either rate or time when light (intensifying screen) exposures are used.

5. List and briefly discuss four factors that influence the speed of x-ray film.

   Ans. a. Film type - the larger the grain size the faster the film.

   b. Processing - time/temperature and developer condition.

   c. Screen type - slow or fast screens, type of phosphor.

   d. X-ray energy - variation of mass attenuation coefficient with energy.

6. List four factors that can affect film-screen contact. How can film-screen contact be checked?

   Ans. a. Warped cassette.

   b. Wrinkled screens.

   c. Foreign bodies (dust, lint, etc.).

   d. Cracked cassette.

   e. Worn felt.

   f. Trapped air.

   Contact can be checked by radiographing 1/8 - 1/4 inch brass or copper mesh.

7. What is the relation between the speed and resolution of a typical calcium tungstate intensifying screen? What screen factors influence speed and resolution?

   Ans. a. As speed increases, resolution decreases.

   b. Screen factors include thickness of phosphor, particle size, screen temperature (speed only).

Name _____

PART II

Answer, in the space provided, any 3 of the 4 questions. Grade value, 20 points each.

1. Discuss the sequence of events that occur when the latent image is formed: 1. by light (intensifying screen) exposure. 2. by direct (x-ray) exposure.

   Ans. 1. Light photon interacts with bromine ion removing valence electron. Electron migrates to sensitivity speck, combines with Ag^+ ion to form metallic silver. Process must be repeated many times for "permanent" latent image.

   2. X-ray photon interacts in emulsion in photoelectric event. Photoelectron interacts in AgBr producing electrons (ionzation) which combine with Ag^+ ions at sensitivity speck (single hit process).

2. The four steps that an automatic x-ray film processor performs in processing an x-ray film are: 1. development, 2. fixation, 3. wash, 4. dry. Discuss the purpose, and the action on the emulsion, of each step.

   Ans. 1. Development - alkali softens gelatin permitting developing agents to enter and provide electrons to convert AgBr grains with latent image to metallic silver.

   2. Fixation - dissolves undeveloped Ag from emulsion, hardens the gelatin, stops action of developer.

   3. Wash - removes processing chemicals.

   4. Dry - dries the radiograph.

3. Radiographic contrast is determined by subject contrast and film (emulsion) contrast. List and briefly discuss the factors that influence subject contrast and film contrast and their overall effect on raiographic contrast.

   Ans. a. Subject contrast - thickness difference, material (absorption) difference, x-ray energy, scattered radiation.

   b. Emulsion contrast - film type, processing, screen type (if used), density level.

   c. Radiographic contrast (density difference) is dependent on all of a. and b.

4. Two means used to reduce the quantity of scattered radiation reaching the x-ray film in radiography of the chest are a grid and an air gap. Describe how both means reduce scattered radiation reaching the film.

Ans. a. Grid - attenuates, in lead strips, radiation scattered at angle, other than 0°, from patient. The higher the grid ratio or finer the grid the greater the reduction.

b. Air gap - increasing the distance of the film from the patient results in inverse-square law (patient is "source" of scatter) decrease. Radiation scattered at "large" angles will not strike the film.

Name _____

GS-463. X-RAY APPLICATIONS
Test No. 2
Total Point Value 120

Part I. Multiple Choice. Circle the letter preceding the one phrase that correctly completes the statement.

Grade value 4 points each.

1. Film (emulsion) contrast is independent of:

   a. the type of film.
   b. the radiographic density.
   c. the processing conditions.
   (d) the kilovoltage used.
   e. none of the above.

2. Increasing the object-film distance will:

   a. decrease magnification.
   (b) decrease sharpness.
   c. decrease contrast.
   d. decrease exposure time.
   e. have no effect on the radiographic image.

3. Grid ratio refers to the ratio of the:

   a. height to width of the lead in the grid.
   b. length to width of the grid.
   c. forward to back speed of movement of a reciprocating grid.
   (d) height to the width of the windows (spacers) between lead strips.
   e. exposure transmitted through the grid to that attenuated by the grid.

4. Film A has a relative speed twice that of film B. If film A requires an exposure of 20 mR for a density of 1.50, the exposure for film B for a density of 1.50 would be:

   (a) 40 mR.
   b. 20 mR.
   c. 10 mR.
   d. 5 mR.
   e. 1 mR.

5. The average gradient of an x-ray film refers to:

   a. the average thickness of the emulsion.
   b. the slope of a straight line drawn tangent to the characteristic curve.
   (c) the slope of a straight line connecting two points of specified density on the characteristic curve.
   d. the slope of the straight line portion of the characteristic curve.
   e. the average exposure necessary to produce a density of 1.0.

6. A 2-2T plaque penetrameter sensitivity means:

   (a) both a thickness and lateral (detail) sensitivity 2 percent of the object thickness.
   b. both the plaque thickness and hole diameter must be two times the object thickness.
   c. a thickness sensitivity 2 percent of the object thickness and a lateral (detail) sensitivity 4 percent of the object thickness.
   d. two penetrameters must be used.
   e. the object to be radiographed is 0.25 inch thick.

7. The use of sensitometric curves to describe film response was proposed by:

   a. Mees and James.
   b. Potter and Bucky.
   (c) Hurter and Driffield.
   d. Eastman and Shepard.
   e. Dean and Mitchell.

8. The Gurney-Mott theory refers to:

   (a) the formation of the latent image.
   b. the process by which AgBr grains with latent image are converted to metallic silver in the developer.
   c. the speed/temperature relation in emulsion mixing.
   d. the fogging of film exposed to Hg vapor.
   e. none of the above.

9. Grid fineness refers to:

   a. the texture of the lead strips and spacers.
   (b) the number of lead strips per inch or per centimeter.
   c. the range of distances over which a focused grid can be used.
   d. the width of the lead strips in the grid.
   e. the height of the lead strips in the grid.

10. Tomography refers to:

   a. radiography of the torso of the body.
   (b) body section radiography.
   c. stereoradiography.
   d. mammography.
   e. radiography of the tomo.

Part II. True-False. If all parts of the statement are true, mark a T on the line preceding the statement. If any part of the statement is false, mark an F on the line preceding the statement.

Grade value 2 points each.

F 1. The use of a grid to reduce scattered radiation reaching the film was developed by Dr. Hollis Potter in 1931.

T 2. A high-speed $CaWO_4$ intensifying screen is usually thicker than a medium speed $CaWO_4$ intensifying screen.

T 3. The lower the temperature of an intensifying screen, the greater will be the light emitted per milliroentgen of exposure.

F 4. In direct (x ray) exposure of film, the x-ray photon ejects a bromine ion from the AgBr grain to form the latent image.

F 5. Scotopic vision in fluoroscopy refers to vision using both rods and cones in the retina.

T 6. Film graininess results from clumping of developed grains.

F 7. Structure mottle refers to the nonuniform dispersion of AgBr grains in the emulsion.

F 8. A film with high contrast will have a low average gradient.

F 9. Interproximal (bite-wing) radiodontic examinations include large areas of maxillae.

T 10. In intra-oral dental radiography, the x-ray film is placed in the oral cavity.

Part III. Discussion/Problems. Answer all questions in the space provided.

Grade value 10 points each.

1. List and briefly describe, four industrial uses of x ray other than radiography.

   Ans.
   1. Fluoroscopy - production line examinations, no permanent record required.
   2. Height-of-fill. - Liquid level in light opaque containers.
   3. Thickness gauging - determine and control thickness of rolled metals.
   4. Diffraction - determine crystal structure.
   5. Emission - characteristic radiation for element determination.

2. From the data in the table shown below, calculate the average gradient for a density range of 0.5 - 2.0 and for a density range of 0.5 - 2.5.

Net Density	Log Exposure
0.25	1.399
0.5	1.558
1.0	1.726
1.5	1.840
2.0	1.946
2.5	2.042

   Ans.

   $\overline{G} = (2.0 - 0.5)/1.946 - 1.558 = 3.87$

   $\overline{G} = (2.5 - 0.5)/2.042 - 1.558 = 4.13$

3. The table below lists the exposures required for three film-screen combinations for a net density of 1.00.

Film-Screen Combination	Exposure-mR
A	0.75
B	1.25
C	2.00

   a. What are the relative speeds of A and C in relation to B?

   Ans. $RS_A = (1.25)\ (100)/0.75 = 167$

   $RS_C = (1.25)\ (100)/2.00 = 62.5$

b. What are the relative exposures of B and C in relation to A?

Ans. $RE_B = (1.25)\ (1)/0.75 = 1.67$

$RE_C = (2.00)\ (1)/0.75 = 2.67$

4. a. List four factors which influence radiographic detail.

Ans.
1. Film contrast.
2. Subject contrast.
3. Geometric factors.
4. Graininess and mottle.
5. Motion.
6. Processing.

b. List four means that can be used to reduce the quantity of scattered radiation reaching the film in medical radiography.

Ans.
1. Use a grid.
2. Use an air gap.
3. Reduce energy (kVp).
4. Reduce field size (area).

c. What is the difference between detail and contrast?

Ans. Detail is the fineness of the image recorded on the film. Contrast is the density difference and what makes detail visible.

5. Figure 1 attached shows an incorrect and incomplete basic x-ray machine circuit diagram. Comlete and correct the diagram.

Ans.
1. HV transformer windings are reversed.
2. kVp meter should be in primary.
3. mA meter on HV transformer center ground.

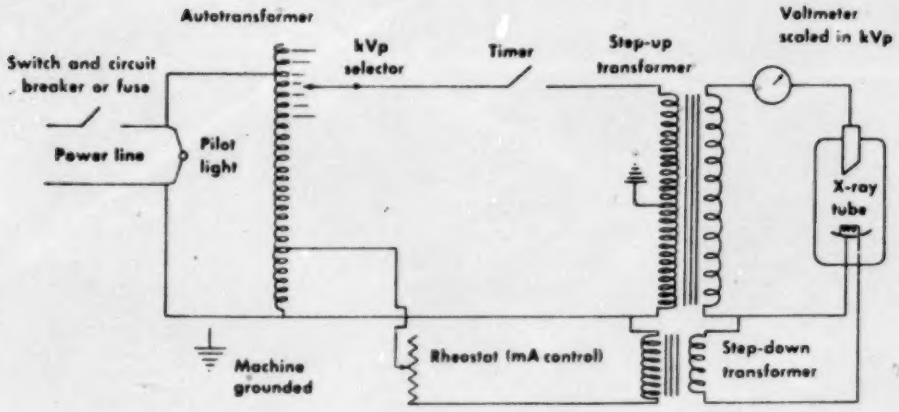
6. Figure 2 attached shows a plot of exposure rate in R/min versus added absorber thickness in mm Al used to determine half-value layer. In one sentence, what is wrong with this plot?

Ans. Exposure rate, R/m, should be plotted as the log or plotted on semi-log graph paper.

HANDOUT

INCORRECT AND DEFICIENT X-RAY MACHINE WIRING DIAGRAM (1)

(To be corrected by Student)



Insert missing parts

Correct titles

Add titles where missing

Figure 1

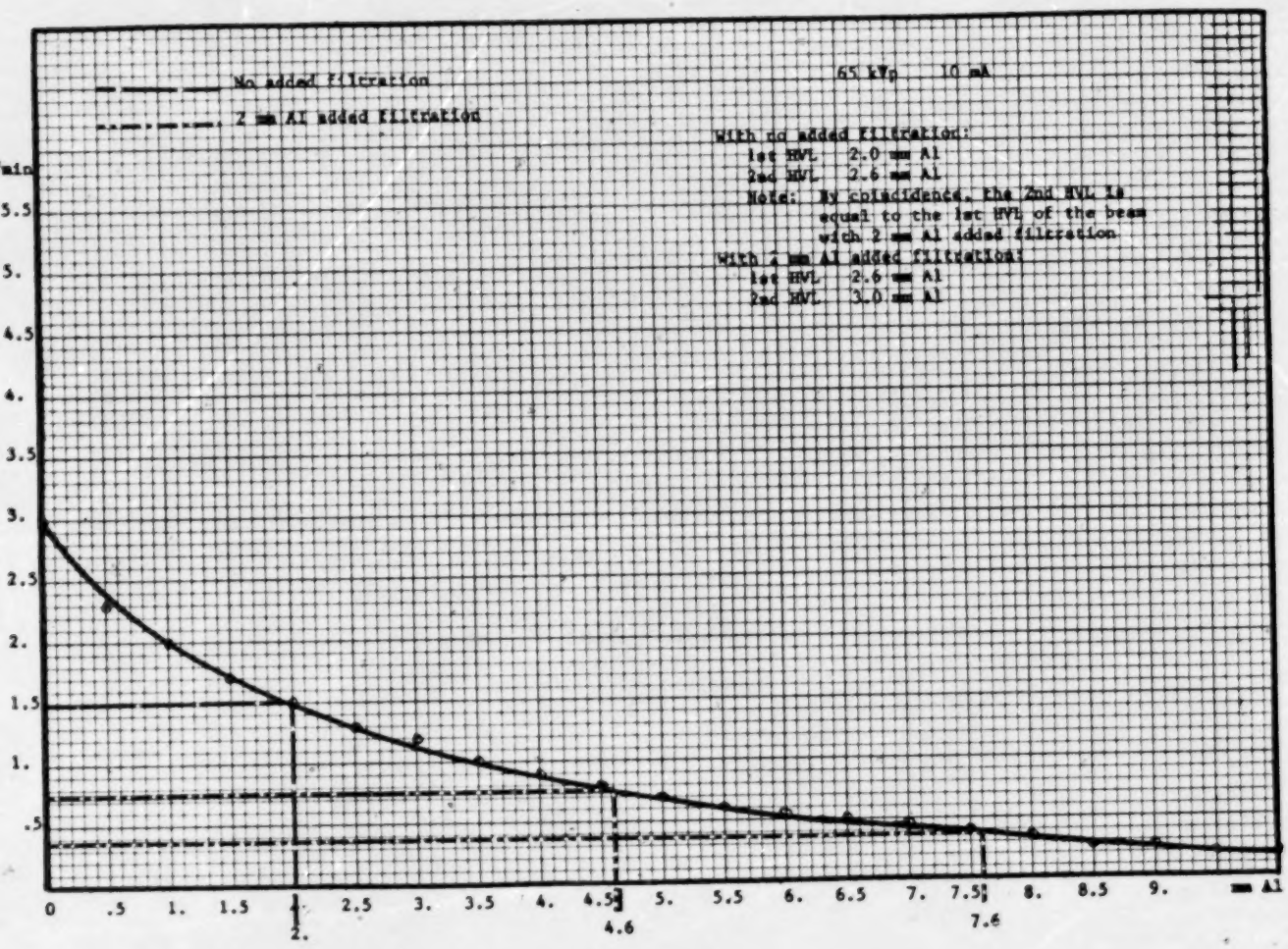

No added filtration
2 mm Al added filtration
65 kVp 10 mA
With no added filtration:
1st HVL 2.0 mm Al
2nd HVL 2.6 mm Al
Note: By coincidence, the 2nd HVL is equal to the 1st HVL of the beam with 2 mm Al added filtration.
With 2 mm Al added filtration:
1st HVL 2.6 mm Al
2nd HVL 3.0 mm Al
mR/min
5.5
5.
4.5
4.
3.5
3.
2.5
2.
1.5
1.
.5
0 .5 1. 1.5 2. 2.5 3. 3.5 4. 4.5 5. 5.5 6. 6.5 7. 7.5 8. 8.5 9. mm Al
2.
4.6
7.6

Figure 2

Name _____

GS-463. X-RAY EXAMINATIONS
Final Examination
Total Point Value 200

Part I. Multiple Choice. Circle the letter or letters preceding the phrase or phrases which correctly completes the statement.

Grade value 5 points each.

1. A film with a high average gradient indicates the film has:

   a. high latitude.
   (b) high contrast.
   c. been exposed without intensifying screens.
   d. coarse AgBr grains.
   e. been fogged because of exposure to light.

2. Radiographic contrast is influenced by:

   (a) subject contrast.
   (b) emulsion contrast.
   (c) scattered radiation.
   (d) film processing conditions.
   (e) the type of intensifying screens used.

3. To radiograph in a single exposure an object having parts of different atomic number and thickness you should use a:

   (a) high kilovoltage.
   b. low kilovoltage.
   c. film with high contrast.
   (d) film with low contrast.
   e. detail intensifying screen.

4. The use of intensifying screens in radiography results in:

   (a) decreased exposure.
   b. increased x-ray tube loading.
   c. increased sharpness.
   d. decreased mottle.
   e. none of the above.

5. Isodose lines, in x-ray therapy, refer to:

   a. the central axis depth dose in the patient.
   b. the exit field dimensions.
   (c) lines of equal dose in the patient.
   d. lines of equal distance from the focal spot.
   e. lines of equal depth within the patient.

6. Radiographic unsharpness because of penumbra will decrease as:

   a. focal spot size decreases.
   b. object-film distance decreases.
   c. source (focal spot)-film distance decreases.
   d. object thickness increases.
   e. object contrast decreases.

7. The exposure technique listed below that has the greatest potential for showing sharpness of structural detail is:

   a. light sensitive (medical) film exposed using detail intensifying screens.

   b. light sensitive (medical) film exposed in a cardboard film holder.

   c. direct exposure (industrial) film exposed in a cardboard film holder.

   d. direct exposure (industrial) film exposed using high speed intensifying screens.

   e. light sensitive (medical) film exposed using high speed intensifying screens.

8. The medical radiographic examination, made without a grid, that would result in the least scattered radiation reaching the film is the:

   a. AP dorsal spine.
   b. lateral lumbar spine.
   c. lateral knee.
   d. lateral dorsal spine.
   e. AP pelvis.

9. The speed of an intensifying screen depends on the:

   a. screen thickness.
   b. screen temperature.
   c. kilovoltage.
   d. type of fluorescent material used.
   e. film processing conditions.

10. The purpose of the yellow dye sometimes used in an intensifying screen is to:

    a. decrease screen deterioration because of x-ray exposure.
    b. increase radiographic sharpness.
    c. increase the speed of the screen.
    d. protect the screen surface.
    e. decrease light persistence from the screen.

11. Film-screen combination A has a relative speed of 25 compared to film-screen combination B at density 1.5. An exposure of 10 mR produced density 1.5 with film-screen combination A.

A. The exposure required to produce density 1.5 with film-screen combination B would be:

a. 40 mR.
b. 25 mR.
c. 4 mR.
(d) 2.5 mR.
e. 1.0 mR.

B. The apparent mottle with combination A compared to combination B, would probably be:

a. increased.
(b) decreased.
c. essentially the same.
d. insufficient information to determine.

C. The apparent graininess of combination A compared to combination B, would probably be:

a. increased.
b. decreased.
c. essentially the same.
(d) insufficient information to determine.

12. Scattered radiation:

a. increases subject contrast.
(b) decreases subject contrast.
c. increases film (emulsion) contrast.
d. decreases film (emulsion) contrast.
e. has no effect on contrast.

Part II. True-False. Mark a T on the line preceding the statement if all parts of the statement are true. If any part of the statement is false, mark F.

Grade value 2 points each.

T 1. "Mustard oil" is the sensitizer used in some x-ray film emulsions.

F 2. The transparent base of current x-ray films is cellulose triacetate.

T 3. The latent image is formed when bromine ions absorb light photons and lose their valence electrons.

F 4. The interaction of a light photon with a AgBr grain is referred to as the "single hit" phenomenon.

F 5. The hardening agent in the fixing solution shrinks and toughens the film base.

F 6. The developer temperature in rapid (90-120 second) automatic x-ray film processors is usually 68° F (20° C).

T 7. A 2 percent industrial penetrameter means that the penetrameter thickness is 2 percent of the specimen thickness.

F 8. Two advantages of using a grid are increased radiographic contrast and decreased patient exposure.

F 9. Rare postage stamps would be radiographed at a high kilovoltage for maximum contrast.

F 10. A person who first starts working at a radiation facility at age 24 would be permitted (by State of Oregon Regulations) to receive a total whole body dose equivalent of 40 rem by age 26.

Part III. Problems-Discussion. Answer all questions in the space provided.

Grade value shown in parenthesis for each question.

(20) 1. Discuss the relation between grid ratio, grid fineness, patient exposure and attenuation of scattered radiation, for grids of ratio 6:1 and 16:1 and fineness 60 lines/inch (24 lines/cm) and 110 lines/inch (43 lines/cm).

Ans. Increasing grid ratio from 6:1 to 16:1 for 60 line grids will reduce the scattered radiation reaching the film and increase patient exposure. The same would be true for a 110 line grid. Increasing fineness from 60 to 110 lines for either ratio will also decrease scatter reaching the film and increase patient exposure.

Since increasing either grid ratio or fineness reduces scatter a higher exposure is necessary for equal radiographic densities. Since scatter reduces object contrast, increasing grid ratio or fineness will increase radiographic contrast hence improve visibility of detail.

(10) 2. List, by function, and briefly describe the four basic ingredients in an x-ray film developing solution.

Ans. 1. Developing agents provide electrons to reduce AgBr grains with latent image to metallic silver.

2. Alkali - activate, soften gelatin.

3. Preservative - reduce oxidation.

4. Restrainer - minimize development of grains without latent image.

(20) 3. Draw, on the same coordinate axis, typical characteristic curves for:

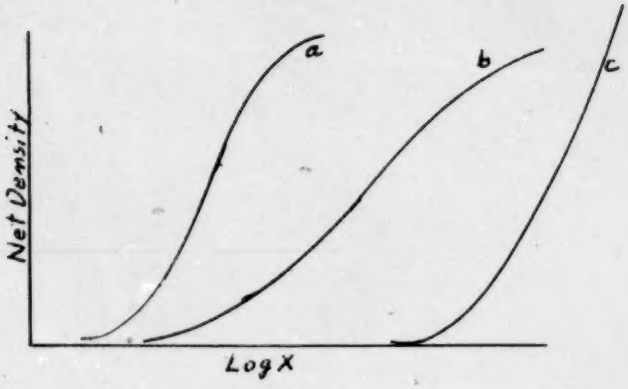
a. Screen-type film exposed using intensifying screens.

b. Screen-type film exposed without intensifying screens.

c. Direct exposure film exposed in a cardboard film holder.

Label the axes and describe the characteristic differences between the curves.

Ans.



a. Has shoulder in readily measurable range.

b. Broader toe and shoulder than a, generally lower contrast.

c. No shoulder in readily measurable density range, increasing contrast as density increases.

(10) 4. What is reciprocity law failure and discuss its significance in medical radiography.

Ans. Reciprocity law fails when, for a constant exposure, the exposure rate and exposure time used do not yield a constant radiographic density. Reciprocity law can fail with light (intensifying screen) exposures but requires extremes of rate and time to fail. Reciprocity law failure is not significant in normal medical radiography.

(10) 5. "Fine" grain and "coarse" grain emulsions require different exposures to produce the same radiographic density. Which film requires the greater exposure? Why?

Ans. "Density" is metallic Ag in the developed emulsion and is a function of the total silver volume. Since the entire grain with latent image is developed, a coarse (large) grain will provide greater density than a fine (small) grain. Fine grain emulsions, therefore, require a greater exposure for the same radiographic density as coarse grain emulsions.

(15) 6. From the data shown below calculate the average gradient for:

a. the density range 0.5 - 2.0
b. the density range 0.5 - 3.0

Is this data for a direct exposure film or a screen-type film? Give the basis for your answer.

Net Density	Log Exposure
0.10	0.48
0.25	0.66
0.50	0.85
1.00	1.05
1.50	1.24
2.00	1.34
2.50	1.58
2.75	1.76
3.00	2.00
3.25	2.60

Ans. $\bar{G}_{0.5 - 2.0}$ $= (2.0 - 0.5)/(1.34 - 0.85) = 1.5/0.49 = 3.06$

$\bar{G}_{0.5 - 3.0}$ $= (3.0 - 0.5)/(2.00 - 0.85) = 2.5/1.15 = 2.17$

Since the average gradient decreases in going from d = 2.0 to 3.0, the characteristic curve has a shoulder and is therefore a "screen-type" film.

7. Define the following:

(5) a. Graininess

Ans. The speckled appearance of a radiograph due to the size of grains or the nonuniform distribution of grains in the emulsion. Visible because of "clumping" of developed grains in the three-dimensional emulsion matrix.

(5) b. Industrial penetrameter thickness sensitivity

Ans. The thickness of the thinnest plaque placed on the specimen divided by the specimen thickness, all times 100

S_T = Plaque thickness/Specimen thickness x 100

(5) c. Photofluorography

Ans. Photographic negative of the image on a fluorescent screen. Used primarily in some "mass chest" x-ray systems wherein the fluoroscopic image is recorded on small, e.g. 35 mm, 10 x 10 cm, etc. film.

(5) d. Resolution of a film-screen combination

Ans. The number of line pairs/millimeter readily visible on radiograph. Determined using a "resolution analyzer" or modulation transfer function techniques.

(5) e. Intensification factor of an intensifying screen

Ans. Ratio of exposure required without intensifying screens to that with intensifying screens for the same radiographic density.

$$IF = X_{\text{no screens}}/X_{\text{with screens}}.$$

APPENDIXES

A. MATERIALS LIST

B. BIBLIOGRAPHY

C. SENSITOMETER

APPENDIX A. MATERIALS LIST

The following is a list of materials needed for each student laboratory group. Major expense items would, of course, be used by all laboratory groups. Material items fabricated in this facility are detailed at the end of this appendix.

Number Required	Item
1	Teaching X-Ray Unit
1	General Electric Experimental X-Ray Unit (150 kVp, 200 mA, single-phase, full-wave rectified unit with continuously variable kVp and mA control)
1	General Electric Horizontal Radiographic Table
1	General Electric DXS-350 X-Ray Unit
1	General Electric DXR-750 X-Ray Unit
1	General Electric Monarch Radiographic Table
1	General Electric CMX-110 Mobile X-Ray Unit
1	General Electric Maxitron 300 X-Ray Unit
1	Vertical Cassette Holder
1	General Electric Dental--100 X-Ray Unit
1	Kodak M-6 X-OMAT automatic x-ray film processor
1	Manual x-ray film processing station (see GS-462 materials list)
1	MacBeth Model TD-102 densitometer
1	35.6 x 43.2 cm (14 x 17 in.) radiographic illuminator
1	High intensity illuminator
1	Set selected industrial specimens
1	Set selected industrial penetrameters
1	3 M Company human phantom
1	Set lead letters and numbers
1	Radiographic Test Block (see USPHS Publication No. 1859)
as required*	12.7 x 17.8 cm (5 x 7 in.) and 20.3 x 25.4 cm (8 x 10 in.) cardboard film holders
as required*	12.7 x 17.8 cm (5 x 7 in.) and 20.3 x 25.4 cm (8 x 10 in.) and 35.6 x 43.2 cm (14 x 17 in.) Par Speed screen cassettes
as required*	20.3 x 25.4 cm (8 x 10 in.) lead screen 0.0125 cm (0.005 in.) cassettes
as required*	12.7 x 17.8 cm (5 x 7 in.) Hi Speed and Detail Cassettes
as required*	Kodak RP Medical X-Ray Film, 12.7 x 17.8 cm (5 x 7 in.), 20.3 x 25.4 cm (8 x 10 in.) and 35.6 x 43.2 cm (14 x 17 in.)
as required*	Kodak 12.7 x 17.8 cm (5 x 7 in.) and 20.3 x 25.4 cm (8 x 10 in.) No Screen film
as required*	Kodak 12.7 x 17.8 cm (5 x 7 in.) X-ray film, type RP/M
as required*	Kodak 12.7 x 17.8 cm (5 x 7 in.) RP Royal Medical X-Ray film

*See laboratory exercises.

Number Required	Item
as required*	12.7 x 17.8 cm (5 x 7 in.) and 20.3 x 25.4 cm (8 x 10 in.) x-ray film processing hangers
as required*	Kodak Periapical Rudia-Tized and Ultra-Speed dental film
as required*	X-ray equipment, film, cardboard holders and cassettes, film processing facilities, and so forth, for Special Project
1	Sensitometer (see Appendix C)

*See laboratory exercises.

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APPENDIX C. SENSITOMETER

The following drawings show the basic parts of the sensitometer used to construct the x-ray film characteristic curves. The sensitometer consists of:

1. A base assembly made of 3/4-inch plywood.
2. A wood frame to position 5- x 7-inch cardboard film holders in the base assembly.
3. A slide assembly made of 1/8-inch thick lead bonded to 1/2-inch plywood.
4. A shield assembly made of 1/8-inch thick lead bonded to 1/2-inch plywood.

The sensitometer was designed for use with our Teaching X-Ray Units but its use is not limited to these units. It can and has been used with other x-ray sources in our Laboratory including our medical radiographic installations.

Construction

1. Base Assembly

   The base assembly is constructed of 3/4-inch plywood. The main portion of the base is 11-7/8 x 14-3/4 inches with a 6-1/8- x 8-1/8-inch hole located as shown. A 5- x 7-inch cassette will fit in this hole. A series of 3/16-inch-diameter holes are drilled in the base at 1/2-inch intervals as shown. These holes align with a hole in the slide assembly (see following) and are used to position the slide in relation to the x-ray film. Two 3/4 x 1-3/4 x 14-1/4-inch wood strips are attached to the top of the base to act as guides for the slide assembly. Scale markings are hand printed on one guide strip and used to establish alignment between the locating hole in the slide assembly and the locating holes in the base. The only critical dimensions in the base assembly are the hole size for the cassette, the space between the two guide strips, and the positions of the locating holes.

2. Frame

   The frame is used with 5- x 7-inch cardboard film holders since the overall dimensions of cardboard holders are less than those of cassettes. The frame is constructed of wood strips glued together as shown. The frame fits in the cassette hole in the base assembly.

3. Slide Assembly

   The slide assembly is constructed of 1/8-inch thick lead bonded to 1/2-inch plywood. A 3-1/8- x 1/2-inch hole is centered in the assembly and the 3/16-inch-diameter locating hole positioned as shown. A slot is cut out of the wood above the lead at each end of the slide for insertion of the lead baffle strip on the shield assembly (see following). The critical dimensions are the 1/2-inch dimension of the hole and the location of the hole, the width of the assembly (close fit between guide strips on base assembly) and the positioning of the 3/16-inch-diameter locating hole. The metal pointer (brass or aluminum) can be attached after assembly to align with the proper scale markings on the base. The

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metal locating pin, inserted through the hole in the slide and into the hole in the base, can be a 1/8 inch - 5/32- inch-diameter nail.

4. Shield assembly

The shield assembly is constructed of 1/8-inch thick lead bonded to 1/2-inch plywood. A 1/8-inch thick strip of lead is attached at one end immediately above the lead on the plywood as shown to provide baffling between the shield and slide assemblies. The critical dimensions are the overall dimensions of the shield. This shield is required because of the limited space in the Teaching X-Ray Unit enclosure. If the sensitometer were used where space is not limited, such as on a radiographic table-top, the "shield" could be made a permanent part of the slide assembly (the length of the slide increased).

Use (with Teaching X-Ray Unit)

1. Center the base assembly on the bottom of the enclosure (center of x-ray field).

2. Place the 5- x 7-inch cassette (or frame with 5- x 7-inch cardboard film holder) in the base.

3. Place the slide on the base between the guide strips. Align the pointer with scale position number 1. Insert the locating pin through the hole in the slide and into the hole in the base.

4. Place the shield on the base at the front between the guides on the base and with the lead baffle strip toward the slide. Mate the shield and slide.

5. Make the x-ray exposure.

6. Remove the locating pin, move the slide and shield to position 2, insert the locating pin, make the x-ray exposure.

7. Repeat this procedure through position 6.

8. At position 7 move the shield from the front to the back of the slide and proceed with the exposures.

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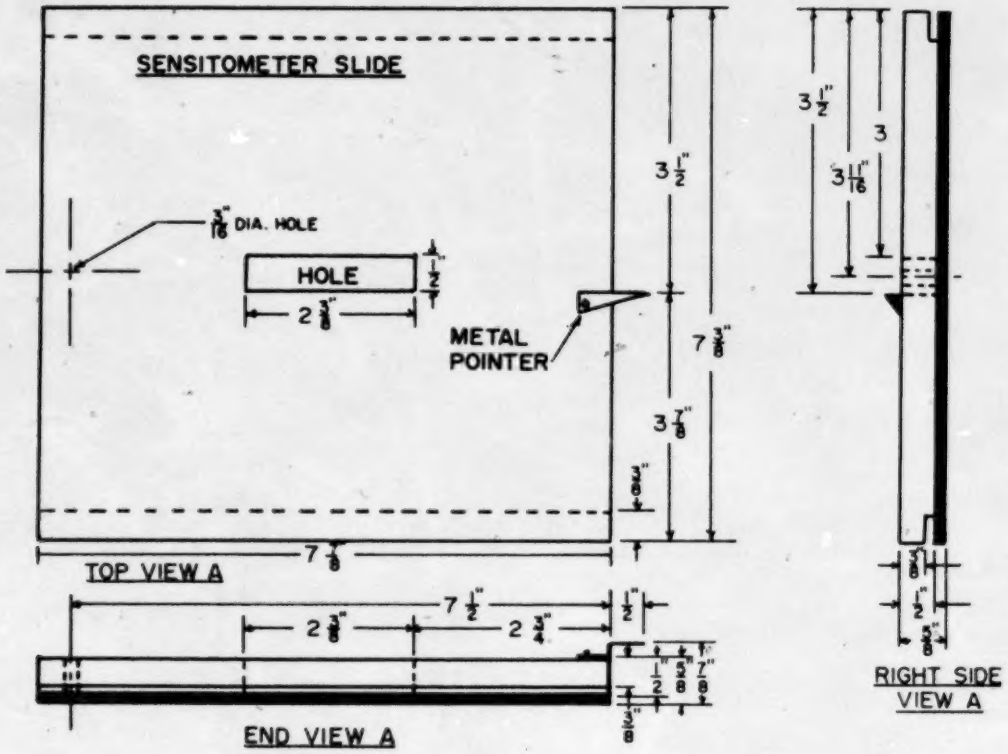
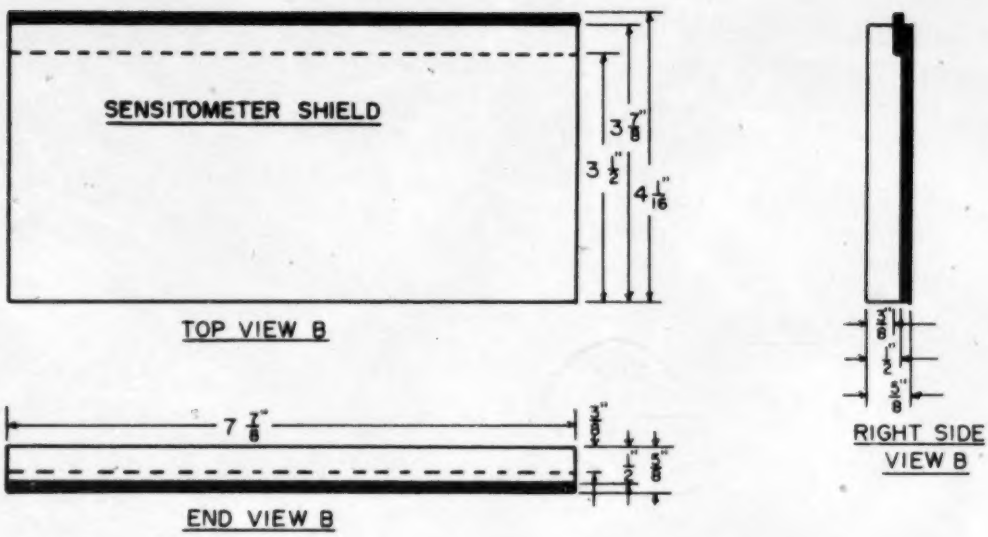


MAT'L: 1/8" LEAD BONDED TO 1/2" PLYWOOD



Sensitometer slide - Sensitometer shield.

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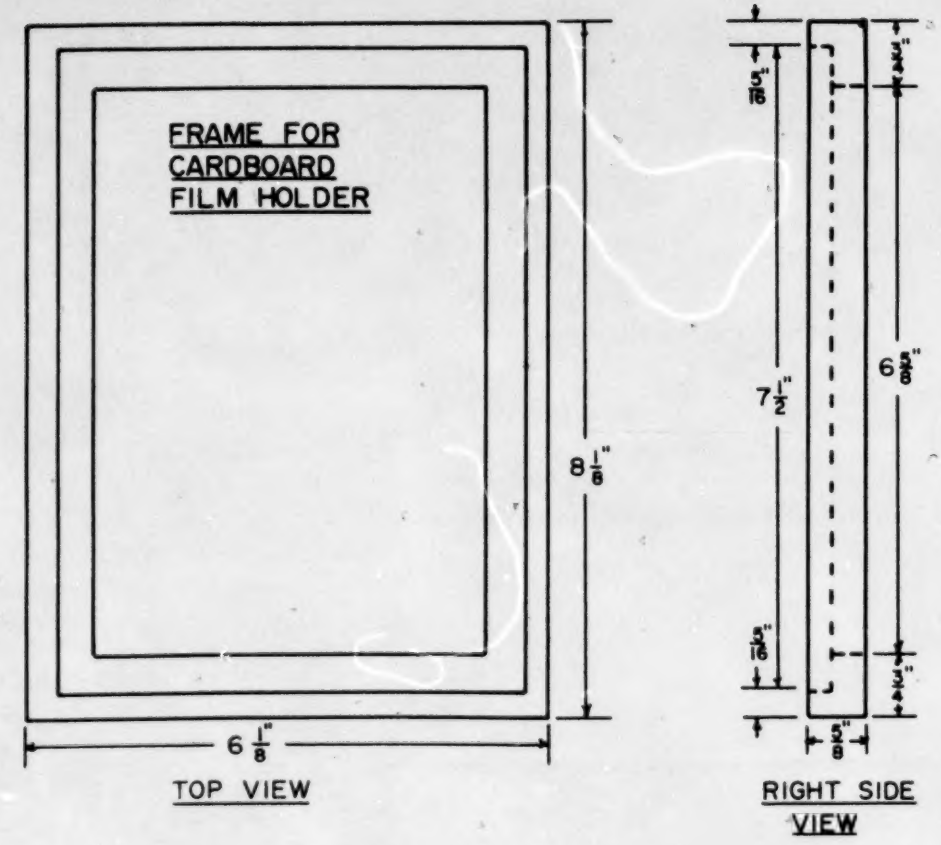
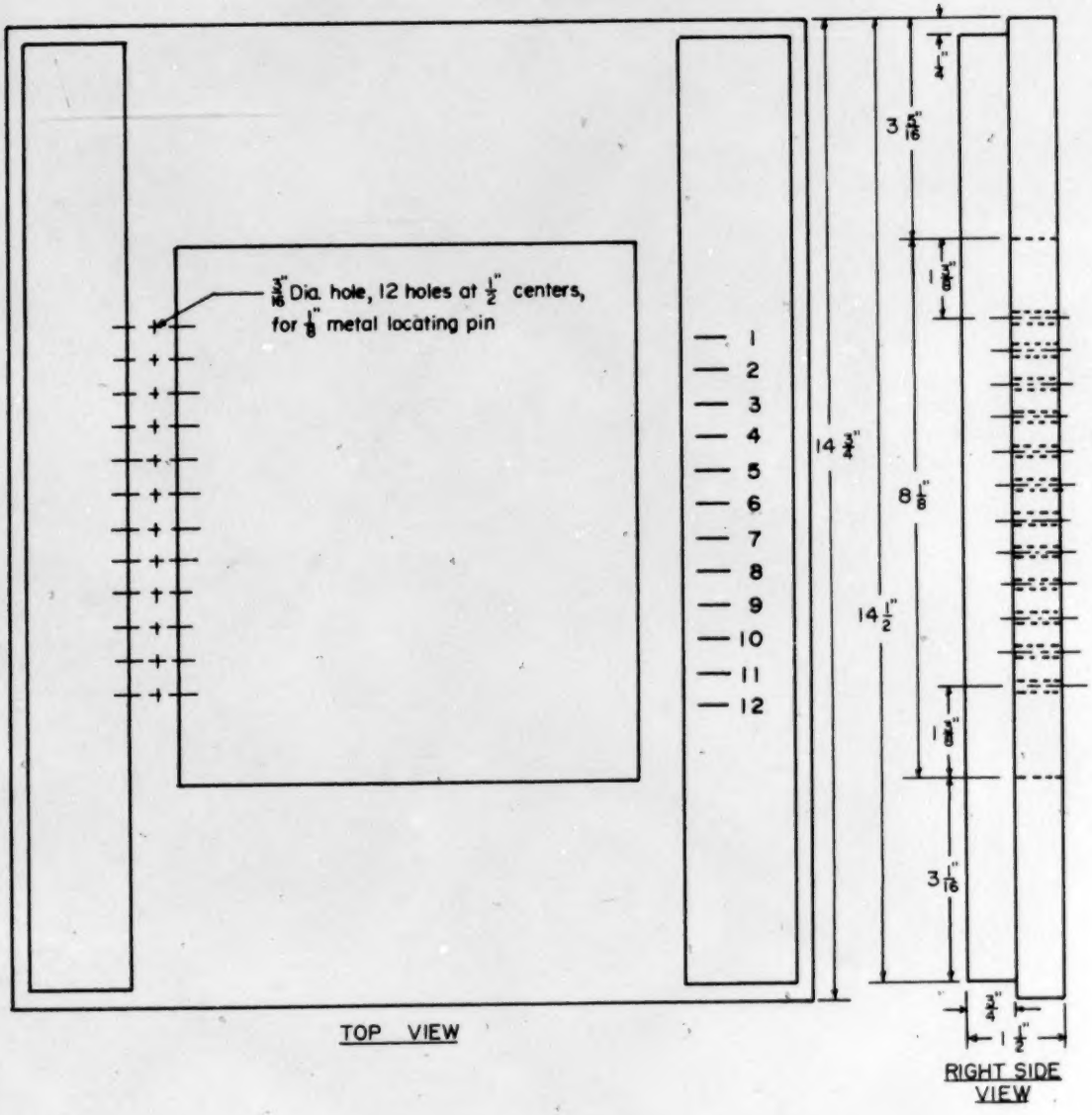
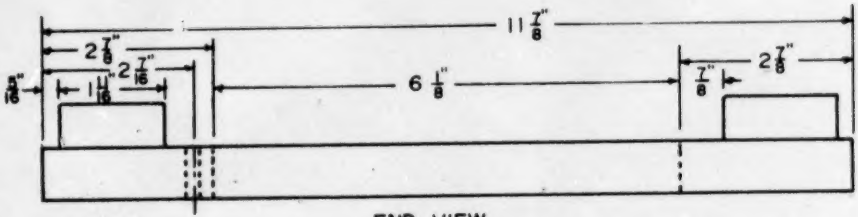


Frame for cardboard film holder.



TOP VIEW

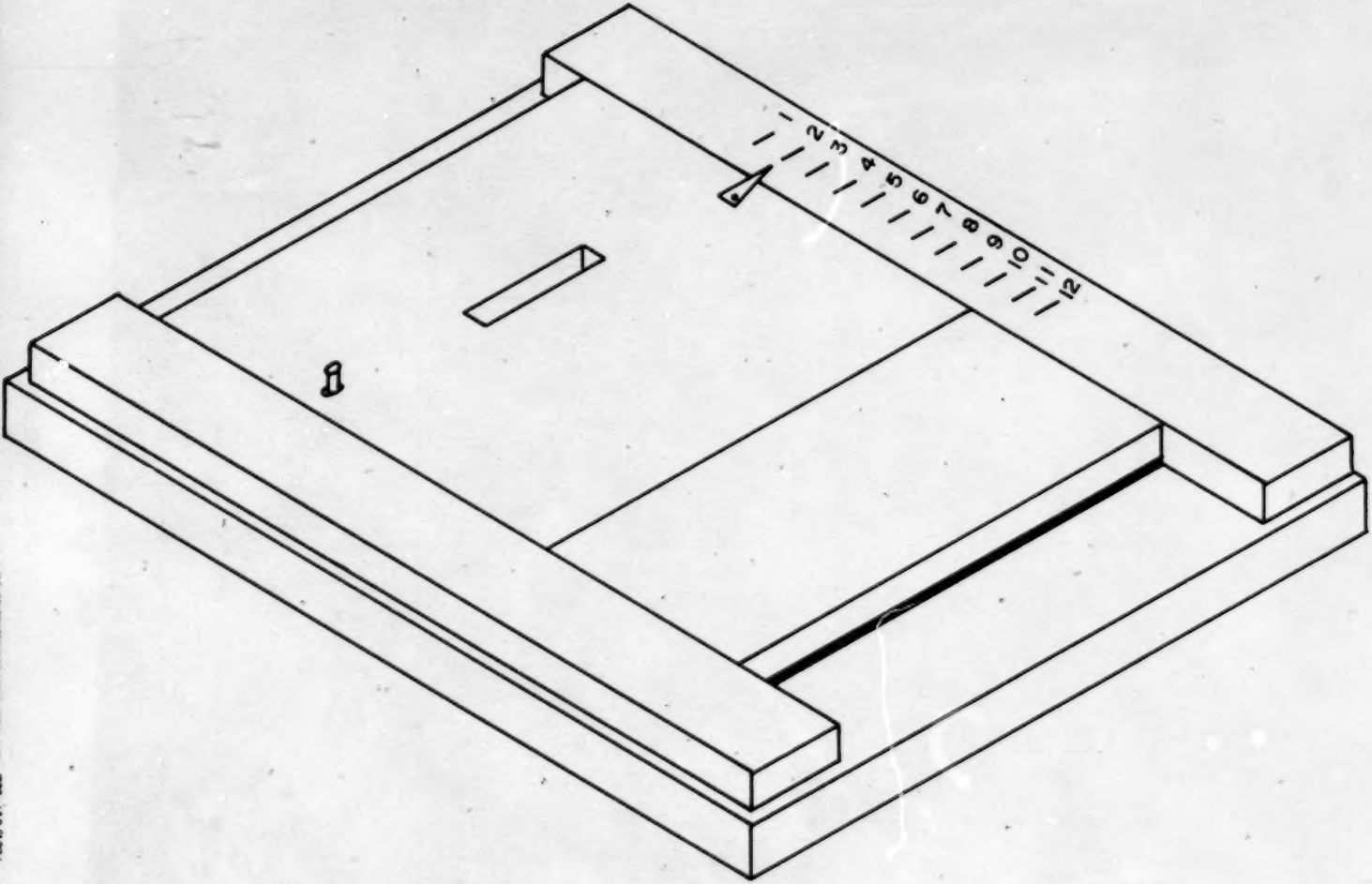
RIGHT SIDE VIEW



END VIEW

MAT'L: 3/4" PLYWOOD

Sensitometer base.



Sensitometer

FDA 77-8005 Report of State and Local Radiological Health Programs, Fiscal Year 1975 (PB 259 947/AS,$4.50).

FDA 77-8006 Nationwide Evaluation of X-Ray Trends: Organ Dose Index System-Instruction Manual.

FDA 77-8007 Radiation Safety Handbook for Ionizing & Nonionizing Radiation (GPO 017-015-00116-4, $1.70) (PB 262 109/AS, mf only).

FDA 77-8008 Imports - Radiation-Producing Electronic Products (GPO 017-015-00120-2, $0.35).

FDA 77-8009 Comparison of Radiation Exposures from Panoramic Dental X-Ray Units (GPO 017-015-00122-9, $0.85) (PB 263 194/AS, $4.00, $3.00 mf).

FDA 77-8010 Biological Effects of Electromagnetic Waves - Selected Papers of the USNC/URSI Annual Meeting - Volume 1 (GPO 017-015-00124-5, $6.50) (PB 268 094/AS, mf only).

FDA 77-8011 Biological Effects of Electromagnetic Waves - Selected Papers of the USNC/URSI Annual Meeting - Volume 2 (GPO 017-015-00125-3, $6.25) (PB 268 095/AS, mf only).

FDA 77-8013 The Mean Active Bone Marrow Dose to the Adult Population of the United States from Diagnostic Radiology (GPO 017-015-00119-9, $1.05) (PB 262 909/AS, mf only).

FDA 77-8014 Evaluation of MDH Model 1015 X-Ray Monitor (GPO 017-012-00241-2, $0.65*, and $1.00**) (PB 263 725/AS, mf only).

FDA 77-8015 Progress in Radiation Protection 1975.

FDA 77-8016 Directory of Personnel Responsible for Radiological Health Programs (superseded by FDA 77-8027).

FDA 77-8017 Nationwide Evaluation of X-Ray Trends: Organ Dose Index System - Radiographic Field Survey Procedures Handbook (GPO 017-015-00121-1, $0.80).

FDA 77-8018 Photographic Quality Assurance in Diagnostic Radiology, Nuclear Medicine, and Radiation Therapy. Volume II - Photographic Processing, Quality Assurance and The Evaluation of Photographic Materials (GPO 017-015-00123-7, $2.20).

FDA 77-8020 Patient Exposure from Diagnostic X Rays: An Analysis of 1972-1974 NEXT Data (PB 267 741/AS, $4.00).

FDA 77-8021 8th Annual National Conference on Radiation Control: Radiation Benefits and Risks: Facts, Issues, and Options (GPO 017-015-00126-1, $5.50) (PB 267 317/AS, mf only).

FDA 77-8023 Radiological Health Training Resources - 1977.

FDA 77-8024 NARM Guides for Naturally Occurring and Accelerator-Produced Radioactive Materials.

FDA 77-8026 Symposium on Biological Effects and Measurement of Radio Frequency/Microwaves.

FDA 77-8027 Directory of Personnel Responsible for Radiological Health Programs (supersedes (FDA 77-8016)).

FDA 77-8028 Diagnostic Radiology Quality Assurance Catalog.

FDA 77-8029 Course Manual for Machine Sources of X Rays (GS-461) (supersedes (FDA 73-8026)).

FDA 77-8030 Course Manual for X-Ray Measurements (GS-462) (supersedes FDA 73-8027).

FDA 77-8031 Course Manual for X-Ray Applications (GS-463) (supersedes FDA 73-8028).

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